Firm-Specific or Household-Specific Sticky Wages in the New Keynesian Model?*

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This paper shows that switching the dominant use of household-specific sticky wages in the New Keynesian model (Erceg, Henderson, and Levin 2000) for firm-specific sticky wages has qualitative and quantitative consequences. First, the model with firm-specific sticky wages incorporates endogenous changes in the rate of unemployment, whereas there is no unemployment with household-specific sticky wages. Secondly, business-cycle fluctuations of wage inflation and the real wage are clearly distinguishable. In particular, the real wage is countercyclical after a demand shock under any sensible calibration with firm-specific sticky wages, whereas the model with household-specific sticky wages requires larger wage stickiness than price stickiness. Finally, optimal monetary policy is more oriented to stabilizing price inflation with firm-specific sticky wages, and is more oriented to stabilizing the output gap and wage inflation with household-specific sticky wages.

JEL Codes: E12, E24, E32, J30.

*I started to work on this paper in 2006 while I was a visiting fellow at the Federal Reserve Bank of St. Louis. I feel completely grateful to the people of the Federal Reserve Bank of St. Louis for their kind invitation and hospitality. I also want to thank James Bullard, Bill Gavin, Marvin Goodfriend, Ben McCallum, Jesus Vazquez, Yi Wen, and two anonymous referees for insightful comments and suggestions. Financial support was provided by the Spanish Ministry of Education and Science (Postdoc Fellowships Program and Research Project SEJ2005-03470/ECON). The opinions expressed in this paper are exclusively mine and do not necessarily reflect those of the Federal Reserve Bank of St. Louis. Author contact: Departamento de Economía, Universidad Pública de Navarra, 31006, Pamplona, Spain. Tel: +34 948 169336; Fax: +34 948 169721; E-mail: mcasares@unavarra.es.

1. Introduction

The New Keynesian framework was initially introduced as a general-equilibrium (microfounded) structure with nominal rigidities on price setting (King and Wolman 1996; Yun 1996). There was a competitive labor market with homogeneous labor and market-clearing wages. Soon it was noticed that a flexible-wage labor market, even combined with sticky prices, brings over some business-cycle patterns that are difficult to find in actual data—mainly, high volatility on nominal and real wages, strongly procyclical real wages, and little persistence on price inflation and output.[1] To dampen wage volatility, most early New Keynesian models were specified with a high labor-supply elasticity to the real wage (as usually assumed in the real-business-cycle [RBC] literature with logarithmic specifications for the leisure component in the utility function). However, the bulk of empirical microevidence suggests that the labor-supply elasticity should be a low positive number (Altonji 1986; Pencavel 1986; and Card 1994), disputing the macrolevel calibration commonly used in the New Keynesian literature.

Staggered-wage contracts may also help to reduce wage volatility.[2] In a well-known paper, Erceg, Henderson, and Levin (2000)—EHL henceforth—describe a New Keynesian model with both staggered prices and staggered-wage contracts that can be optimally adjusted subject to some constant probability à la Calvo (1983).[3,4]

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[1]See Jeanne (1998), Taylor (1999), Chari, Kehoe, and McGrattan (2000), Casares (2002), and Krause and Lubik (2007).

[2]Other sources of wage rigidities, such as efficiency wages (Danthine and Kurmann 2004) or search and matching frictions (Krause and Lubik 2007), also have been recently incorporated into the labor market of the New Keynesian model.

[3]The Calvo (1983) constant-probability assumption is frequently taken in New Keynesian models because it results in a simple and comprehensive inflation equation: the so-called New Keynesian Phillips curve (Walsh 2003, chap. 5). In turn, inflation fluctuates in the New Keynesian model, responding to changes in current and expected future real marginal costs.

[4]Other authors use Taylor (1980) staggered-price contracts with a predetermined length (Chari, Kehoe, and McGrattan 2000; Huang, Liu, and Phaneuf 2004), and some others follow Rotemberg (1982) to assume a quadratic price-adjustment cost function to slow down price adjustments (Ireland 2003). In all cases, the resulting price-inflation dynamics are similar to those obtained with the dominant Calvo-style pricing scheme.

Households act as wage setters and firms as price setters.[5] Thus, each household owns one differentiated type of labor service and can decide on its nominal-wage rate, provided the arrival of the adequate Calvo-type market signal. As a result, the dynamics of wage inflation can be formulated in a single forward-looking equation governed by the gap between the aggregate marginal rate of substitution of households and the real wage. The EHL model with household-specific sticky wages has received empirical support (Galí, Gertler, and López-Salido 2001; Rabanal and Rubio-Ramírez 2005) and is becoming a preeminent model for monetary policy analysis (Amato and Laubach 2003; Smets and Wouters 2003; Woodford 2003; Giannoni and Woodford 2004; Christiano, Eichenbaum, and Evans 2005; Levin et al. 2006; Casares 2007a).

This paper describes one variant for a sticky-wage New Keynesian model in which firms are the wage-setting actors instead of households. Wage contracts will be reset only in cases when the firm is able to post the optimal price, attaching the Calvo-style staggered-prices scheme also to staggered wages. As in Bénassy (1995), firms will offer households the nominal wage that matches their labor demand with the households' labor supply. These firm-specific sticky wages result in a wage-inflation equation different from that obtained in the EHL model with household-specific sticky wages. In particular, wage-inflation fluctuations are influenced by two real-wage gaps: the household-related gap between the marginal rate of substitution and the real wage (also present in the EHL model) and the firm-related gap between labor productivity and the real wage (absent in the EHL model).

Furthermore, firm-specific sticky wages bring to the New Keynesian model an endogenous measure of unemployment due to the separation between demand and supply of labor in the fraction of wage contracts that cannot be renegotiated over the current period. The unemployment rate is then obtained as the percent difference between economy-wide labor supply and labor demand. In recent years, several papers have already shown how to incorporate unemployment into a New Keynesian structure by attaching a labor

[5] The assumption of providing households with market power to set wages had already been taken in Blanchard (1986), Rankin (1998), and Ascari (2000).

market with matching frictions à la Mortensen-Pissarides (1994).[6] In those papers, unemployment arises as a result of having search costs and matching frictions in the labor market. This paper shows the alternative of nominal rigidities on the firm-specific wage-setting procedure to explain the presence of unemployment in the labor market.[7]

The quantitative implications of having either firms or households as wage-setting actors are examined within a complete New Keynesian model with sticky wages. Thus, the business-cycle properties of the EHL model (households set wages) are compared to those of the model with wage-setting firms. Apart from the key difference on the absence or presence of unemployment, we will show how wage inflation and the real wage respond in a substantially different way to both supply and demand shocks. Special attention will be focused on the real-wage business cycle. Sumner and Silver (1989) provide empirical arguments that explain the slight procyclicality of the real wage observed in the U.S. economy as a combined reaction to supply and demand shocks. They show that the real wage is procyclical in periods dominated by supply shocks, whereas it behaves countercyclically in periods when output fluctuations are driven by demand shocks.[8] The impulse-response functions obtained in the New Keynesian model with firm-specific sticky wages provide the kind of real-wage reactions consistent with the Sumner-Silver hypothesis. This result is not found in the baseline calibration of the EHL model with the same level of price and wage stickiness because the real wage is procyclical after a demand shock. The latter is reversed and the EHL model also replicates the Sumner-Silver hypothesis when wage stickiness is higher than price stickiness to let prices react more strongly than wages and obtain a countercyclical real wage.

[6] A list of those papers should include Christoffel and Linzert (2005), Gertler and Trigari (2006), Krause and Lubik (2007), and Kuester (2007).

[7] Blanchard and Galí (2007) also introduce unemployment in a New Keynesian model by assuming rigidities on the aggregate real wage based on one ad hoc formulation.

[8] Fleischman (1999) corroborates these results in his empirical analysis. Bordo, Erceg, and Evans (2000) use a sticky-wage model to argue that during the Great Depression the real wage moved anticyclically in response to a monetary contraction, which is one example of a demand-side shock.

The consequences of firm-specific or household-specific sticky wages for the optimal design of monetary policy in the New Keynesian model are also discussed in this paper. Following Woodford (2003, chap. 8) and Giannoni and Woodford (2004), optimal monetary policy can be obtained by minimizing a welfare-theoretic intertemporal loss function subject to a set of model equations. We compute the optimal monetary policy in the two sticky-wage variants and compare their stabilizing results. In addition, the performance of an instrument Taylor (1993)-type rule is examined both for a (baseline) standard representation and also for one specification that uses optimized coefficients in accordance with optimal monetary policy. The EHL model implies an optimal policy that stabilizes almost completely the output gap with a very high reaction coefficient in the Taylor-type rule. By contrast, the model with firm-specific sticky wages has an optimal monetary policy with a stronger concern on stabilizing price inflation and more output-gap variability as a result. In both sticky-wage cases, the optimized Taylor-type rule provides a stabilizing performance only slightly inferior to that under the optimal monetary policy.

The remaining sections of the paper are organized as follows. Section 2 describes how to introduce sticky wages that are linked to the staggered-pricing behavior of monopolistically competitive firms and how these firm-specific sticky wages explain the presence of unemployment in the labor market. In section 3, we derive the price-inflation equation with firm-specific sticky wages, which involves terms on expected next period's inflation, the real marginal costs, and the rate of unemployment. The complete New Keynesian models with either firm-specific or household-specific sticky wages are outlined in section 4 with numerical values assigned to the structural parameters mostly borrowed from EHL (2000). Sections 5 and 6 are devoted to carrying out the business-cycle and monetary policy comparisons of the two sticky-wage variants. Section 7 concludes with a review of the major findings and contributions of the paper.

2. Firm-Specific Sticky Wages and Unemployment

Let us begin the analysis by describing the wage-setting process of monopolistically competitive firms á la Dixit and Stiglitz (1977), which may jointly decide the price and the nominal wage. Price stickiness causes output, labor demand, and prices to be firm specific because these variables would depend on when was the last time a firm was able to set the optimal price. In principle, if firms can also decide on the nominal wage, they will post values subordinated to the pricing decision and the upcoming labor-demand constraint.

For explanatory purposes, we can split this connection between prices and wages set at the firm into three separate stages. First, the firm-specific price of some i-th firm, $P_t(i)$, determines the amount of output produced by the firm, $y_t(i)$, at the Dixit-Stiglitz demand curve. The higher the price, the lower the output demand with a constant elasticity. Given a production technology, labor demand, $n_t^d(i)$, is then determined as the amount of work hours that must be employed to produce the given level of output. Labor demand, therefore, increases with output. Finally, the labor supply provides the nominal wage, $W_t(i)$, that the firm must set to convince the household to work the number of hours determined by labor demand. Since labor supply responds positively to a wage increase, the firm will offer higher wages when labor demand is rising. In a schematic way, $P_t(i)$ and $W_t(i)$ are connected through this chain:

$$P_t(i) \overset{\textit{Demand (-)}}{\longrightarrow} y_t(i) \overset{\textit{Technology (+)}}{\longrightarrow} n_t^d(i) \overset{\textit{Labor supply (+)}}{\longrightarrow} W_t(i).$$

As a result, the subordinate wage, $W_t(i)$, takes the value obtained when matching the firm-specific labor demand with the household's labor supply. Therefore, a labor-demand equation, a labor-supply curve, and one equilibrium condition are required for the computation of $W_t(i)$.

We start by describing the labor-supply behavior. Unlike the EHL (2000) model that bears household-specific labor, the assumption of firm-specific wages is consistent with an economy where identical households own all the heterogeneous labor services, while firms only demand one differentiated type of labor.[9] Thus, prices

[9]The assumption of firm-specific labor has been recently introduced in the New Keynesian literature. Thus, Woodford (2003, chap. 3) and Matheron (2006) take this assumption with Calvo staggered prices and fully flexible nominal wages.

and nominal wages are set at the firm, whereas households make optimal substitutions across quantities of differentiated consumption goods and labor services.[10] The following separable utility function ranks preferences between bundles of consumption, c_t, and bundles of labor services supplied, n_t^s, for the representative household:

$$U\left(\chi_t, c_t, n_t^s\right) = \exp(\chi_t)\frac{c_t^{1-\sigma}}{1-\sigma} - \Psi\frac{\left(n_t^s\right)^{1+\gamma}}{1+\gamma}, \tag{1}$$

where $\sigma, \Psi, \gamma > 0.0$ and χ_t is the AR(1) preference shock, $\chi_t = \rho_\chi \chi_{t-1} + \varepsilon_t^\chi$ with $\varepsilon_t^\chi \sim N(0, \sigma_{\varepsilon^\chi})$, that affects utility from consumption. The bundles of consumption and labor in (1) are obtained using Dixit-Stiglitz aggregators over differentiated consumption goods and labor services, $c_t = \left[\int_0^1 c_t(i)^{\frac{\theta_p - 1}{\theta_p}} di\right]^{\frac{\theta_p}{\theta_p - 1}}$ and $n_t^s = \left[\int_0^1 n_t^s(i)^{\frac{1+\theta_w}{\theta_w}} di\right]^{\frac{\theta_w}{1+\theta_w}}$. The budget constraint for this representative household can be written in nominal terms as follows:

$$\int_0^1 W_t(i) n_t^s(i) di = \int_0^1 P_t(i) c_t(i) di + (1 + R_t)^{-1} B_{t+1} - B_t, \tag{2}$$

which indicates that labor income on the left-hand side of (2) is spent on purchases of consumption goods and on increasing the amount of risk-free bonds, $(1 + R_t)^{-1} B_{t+1} - B_t$, that yield a nominal interest rate, R_t. Using Dixit-Stiglitz aggregators of the price level and the nominal wage, $P_t = \left[\int_0^1 P_t(i)^{1-\theta_p} di\right]^{\frac{1}{1-\theta_p}}$ and $W_t = \left[\int_0^1 W_t(i)^{1+\theta_w} di\right]^{\frac{1}{1+\theta_w}}$, it can be proved that optimal households' substitutions imply that $\int_0^1 W_t(i) n_t^s(i) di = W_t n_t^s$ and $\int_0^1 P_t(i) c_t(i) di = P_t c_t$. Inserting these results in (2) and dividing by

De Walque, Smets, and Wouters (2006) study the implications of firm-specific labor in a model with Taylor contracts on prices set by firms and wages set by households. Finally, Casares (2007b) also assumes firm-specific labor services in a model with flexible prices and Calvo sticky wages set by either households or firms.

[10] In other words, firms are both monopolistic competitors on providing consumption goods and monopsonistic competitors on demanding labor services.

P_t, the budget constraint in real magnitudes—i.e., units are bundles of consumption goods—becomes

$$\frac{W_t}{P_t}n_t^s = c_t + (1+R_t)^{-1}\frac{B_{t+1}}{P_t} - \frac{B_t}{P_t}. \tag{3}$$

Using (1) in an infinite time horizon with rational expectations, the representative household wants to maximize $E_t \sum_{j=0}^{\infty} \beta^j U(\chi_{t+j}, c_{t+j}, n_{t+j}^s)$ subject to budget constraints (2) or (3) in period t and future periods.[11] The first-order conditions for the optimal decision on the number of bundles of consumption goods, c_t, and labor services, n_t^s, respectively, are

$$\exp(\chi_t)c_t^{-\sigma} - \xi_t = 0, \tag{4a}$$

$$-\Psi\left(n_t^s\right)^{\gamma} + \xi_t\frac{W_t}{P_t} = 0, \tag{4b}$$

where ξ_t is the Lagrange multiplier of the budget constraint. The value of ξ_t implied by (4a) can be substituted in (4b) and terms can be rearranged to obtain the following labor-supply function for bundles of labor services:

$$n_t^s = \left(\frac{\exp(\chi_t)W_t/P_t}{\Psi c_t^{\sigma}}\right)^{1/\gamma}. \tag{5}$$

Meanwhile, the first-order conditions on the i-th specific type of consumption good and on the i-th specific type of labor service, respectively, are

$$\exp(\chi_t)c_t^{-\sigma}\left(\frac{c_t}{c_t(i)}\right)^{\frac{1}{\theta_p}} - \xi_t\left(\frac{P_t(i)}{P_t}\right) = 0, \tag{6a}$$

$$-\Psi\left(n_t^s\right)^{\gamma}\left(\frac{n_t^s(i)}{n_t^s}\right)^{\frac{1}{\theta_w}} + \xi_t\frac{W_t(i)}{W_t}\frac{W_t}{P_t} = 0. \tag{6b}$$

Combining (4a) and (6a) to eliminate ξ_t leads to the Dixit-Stiglitz demand function

$$c_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta_p} c_t, \tag{7}$$

[11] As usual, the discount factor is constant at $\beta < 1.0$ and future values are foreseen by applying the rational-expectations operator E_t.

where θ_p is the constant elasticity of substitution for consumption goods. Analogously, a supply curve for the specific type of labor service can be derived by combining (4b) and (6b):

$$n_t^s(i) = \left(\frac{W_t(i)}{W_t}\right)^{\theta_w} n_t^s, \tag{8}$$

in which θ_w is the constant elasticity of substitution across differentiated labor services. Taking logs on both sides of (8) yields

$$\widehat{n}_t^s(i) = \theta_w\left(\widehat{W}_t(i) - \widehat{W}_t\right) + \widehat{n}_t^s, \tag{9}$$

where variables topped with a hat denote the log of the original variable (e.g., $\widehat{W}_t(i) = \log W_t(i)$). The (log-linear) labor-supply curve (9) indicates how households are willing to provide more specific labor services whenever their relative nominal wage increases or, alternatively, whenever there is a higher supply of bundles of labor.

Shifting to labor demand, let us suppose that all firms have access to a production technology with decreasing marginal productivity of labor and a technology shock. Thus, the production function is written for the i-th firm as follows:

$$y_t(i) = \left(\exp(z_t) n_t^d(i)\right)^{1-\alpha}, \tag{10}$$

with $0.0 < \alpha < 1.0$. The amount of firm-specific output, $y_t(i)$, depends on the firm-specific labor demand, $n_t^d(i)$, and on the exogenous AR(1) technology shock, $z_t = \rho_z z_{t-1} + \varepsilon_t^z$ with $\varepsilon_t^z \sim N(0, \sigma_{\varepsilon^z})$. Firms are monopolistic competitors á la Dixit and Stiglitz (1977), with labor demand determined by the level of output. Therefore, we recall the Dixit-Stiglitz demand equation, (7), then use the market-clearing condition, $c_t(i) = y_t(i)$, and the Dixit-Stiglitz output aggregator, $y_t = \left[\int_0^1 y_t(i)^{\frac{\theta_p - 1}{\theta_p}} di\right]^{\frac{\theta_p}{\theta_p - 1}}$, to obtain

$$y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta_p} \left[\int_0^1 y_t(i)^{\frac{\theta_p - 1}{\theta_p}} di\right]^{\frac{\theta_p}{\theta_p - 1}}.$$

Then inserting the production function (10), we find

$$\left(\exp(z_t)n_t^d(i)\right)^{1-\alpha} = \left(\frac{P_t(i)}{P_t}\right)^{-\theta_p}\left[\int_0^1 \left(\exp(z_t)n_t^d(i)\right)^{\frac{(1-\alpha)(\theta_p-1)}{\theta_p}} di\right]^{\frac{\theta_p}{\theta_p-1}}.$$

The last expression can be log-linearized to reach the following labor-demand equation:

$$\widehat{n}_t^d(i) = -\frac{\theta_p}{1-\alpha}\left(\widehat{P}_t(i) - \widehat{P}_t\right) + \widehat{n}_t, \tag{11}$$

where $\widehat{n}_t = \int_0^1 \widehat{n}_t^d(i)di$ is the log of aggregate labor.[12]

Now, we are ready to obtain the subordinate nominal wage. As in Bénassy (1995), the wage contract is set at the value that matches labor supply with labor demand. Before introducing wage stickiness, let us examine the wage-setting behavior with fully flexible wages. If all firms can reset their wage contracts every period, the matching condition $\widehat{n}_t^d(i) = \widehat{n}_t^s(i)$, where $\widehat{n}_t^s(i)$ is given by (9) and $\widehat{n}_t^d(i)$ by (11), leads to this (log of) the nominal wage:

$$\widehat{W}_t(i) = \widehat{W}_t - \frac{\theta_p}{\theta_w(1-\alpha)}\left(\widehat{P}_t(i) - \widehat{P}_t\right). \tag{12}$$

There is a negative relationship between the firm-specific optimal price, $\widehat{P}_t(i)$, and the subordinate nominal wage, $\widehat{W}_t(i)$. Those firms that set prices above the aggregate price level will demand less labor and will reduce the nominal wages offered to households in order to reach a perfect match of labor supply with their decreasing demand for labor. With flexible wages, the labor market is in equilibrium because all the pairs of differentiated labor supply and labor demand are well matched.

However, the presence of nominal rigidities on firm-specific wage setting brings in situations of disequilibrium in the labor market regarding the fraction of wage contracts that are not revised. For simplicity, we extend the sticky-price scheme á la Calvo (1983)

[12] Therefore, labor demand becomes the amount of labor effectively employed as typical from a Keynesian economy.

to the resetting of the subordinate wage contracts.[13] Hence, there is a constant probability, η, that the firm is not able to optimally adjust prices, which also causes the lack of wage adjustment. In those situations, next period's prices and nominal wages are left unchanged, assuming that the steady-state rate of inflation is 0 and price/wage indexations do not proceed. With this price and wage stickiness, the wage-setting procedure of labor matching becomes forward looking in order to take into account expectations on future amounts of labor demand and supply attached to the unrevised price and wage. Assuming that the i-th firm can optimize in period t, the labor-matching wage is set at the value that satisfies

$$E_t^{\eta} \sum_{j=0}^{\infty} \beta^j \eta^j \left[\widehat{n}_{t+j}^d(i) - \widehat{n}_{t+j}^s(i)\right] = 0, \tag{13}$$

where E_t^{η} denotes the rational-expectations operator conditional to not being able to change the price and the wage contract in future periods. Inserting the labor-demand equation (9) for any $t+j$ period in (13), and also the labor-supply curve (11) for any $t+j$ period, results in the following (log of) the labor-matching nominal wage:

$$\widehat{W}_t(i) = -\frac{\theta_p}{\theta_w(1-\alpha)}\widehat{P}_t(i) + (1-\beta\eta)E_t\sum_{j=0}^{\infty}\beta^j\eta^j\left(\widehat{W}_{t+j} + \frac{\theta_p}{\theta_w(1-\alpha)}\widehat{P}_{t+j} - \frac{1}{\theta_w}\left(\widehat{n}_{t+j}^s - \widehat{n}_{t+j}\right)\right) \tag{14}$$

that collapses to (12) in the absence of nominal Calvo-type rigidities ($\eta = 0.0$). As in Blanchard and Galí (2007), let us define the rate of unemployment as follows:[14]

$$u_t = \widehat{n}_t^s - \widehat{n}_t, \tag{15}$$

which can be noticed in (14) referring to the $t+j$ period. As mentioned above, firm-specific sticky wages explain the separation

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[13] In the absence of optimal pricing, the firm would have to demand as many labor units as required by the Dixit-Stiglitz demand curve at the current (non-optimal) price, whereas households would have to work that number of hours with no wage revision. Neither party would optimize in their choices of labor.

[14] The rate of unemployment could also have been introduced as $u_t = 1 - \frac{n_t}{n_t^s}$. If so, (15) would be reached by taking logs on both sides of the equivalent expression $1 - u_t = \frac{n_t}{n_t^s}$ and then assuming that $\log(1-u_t) \simeq -u_t$ because u_t is a sufficiently small number.

between the supply of labor bundles and their effective labor demand coming from the unrevised wage contracts. Such an endogenous unemployment is not present in EHL (2000), because the household-specific wage-setting behavior leads to a perfect matching for all pairs of differentiated labor demand and labor supply despite having wage stickiness.

Let us continue the analysis to derive the wage-inflation equation with firm-specific sticky wages. Aggregate wage inflation can be defined as $\pi_t^w = \widehat{W}_t - \widehat{W}_{t-1}$ and, in a similar way, aggregate price inflation as $\pi_t^p = \widehat{P}_t - \widehat{P}_{t-1}$. These definitions allow us to write $\widehat{W}_{t+j} = \widehat{W}_t + \sum_{k=1}^{j} \pi_{t+k}^w$ and $\widehat{P}_{t+j} = \widehat{P}_t + \sum_{k=1}^{j} \pi_{t+k}^p$, which can be inserted into (14) to yield

$$\widehat{W}_t(i) - \widehat{W}_t = -\frac{\theta_p}{\theta_w(1-\alpha)}\big(\widehat{P}_t(i) - \widehat{P}_t\big) - \frac{1-\beta\eta}{\theta_w} E_t \sum_{j=0}^{\infty} \beta^j \eta^j u_{t+j} + E_t \sum_{j=1}^{\infty} \beta^j \eta^j \left(\pi_{t+j}^w + \frac{\theta_p}{\theta_w(1-\alpha)}\pi_{t+j}^p\right). \tag{16}$$

As a well-known result obtained for the Calvo pricing scheme, aggregate price inflation is linked to the log-difference between the optimal price and the aggregate price level:[15]

$$\pi_t^p = \frac{1-\eta}{\eta}\big(\widehat{P}_t(i) - \widehat{P}_t\big). \tag{17}$$

With firm-specific wages, the Calvo fixed-probability scheme for sticky prices also determines the allocation of differentiated wages coming from the (subordinate) sticky wages. Thus, wage inflation is analogously related to the log-difference between the subordinate nominal wage and the aggregate nominal wage,

$$\pi_t^w = \frac{1-\eta}{\eta}\big(\widehat{W}_t(i) - \widehat{W}_t\big). \tag{18}$$

[15] One can reach this result by log-linearizing the aggregate-price-level definition with Calvo-style pricing frictions, $P_t = [(1-\eta)P_t(i)^{1-\theta_p} + \eta P_{t-1}^{1-\theta_p}]^{\frac{1}{1-\theta_p}}$, where P_t is the aggregate price level and $P_t(i)$ is the optimal price.

Combining (16), (17), and (18), we can obtain a relationship between wage inflation and price inflation of this kind:[16]

$$\pi_t^w = \beta E_t \pi_{t+1}^w - \frac{\theta_p}{\theta_w(1-\alpha)}\left(\pi_t^p - \beta E_t \pi_{t+1}^p\right) - \frac{(1-\beta\eta)(1-\eta)}{\eta\theta_w} u_t, \tag{19}$$

which determines wage-inflation fluctuations with firm-specific sticky wages. Using (19) to compute π_{t+j}^w and then substituting the result in (16) yields

$$\widehat{W}_t(i) - \widehat{W}_t = -\frac{\theta_p}{\theta_w(1-\alpha)}\left(\widehat{P}_t(i) - \widehat{P}_t\right) - \frac{1-\beta\eta}{\theta_w} E_t \sum_{j=0}^{\infty} \beta^j u_{t+j}. \tag{20}$$

The relative firm-specific wage contract, $\widehat{W}_t(i) - \widehat{W}_t$, depends on the current relative firm-specific price, $\widehat{P}_t(i) - \widehat{P}_t$, with a negative sign of dependence. If the i-th firm set an optimal price higher than the aggregate price level, its labor demand would fall in response to the decay in the amount of production given by the Dixit-Stiglitz demand curve. Thus, the firm would set a lower nominal-wage contract to clear the supply of labor with its decreasing labor demand. Another determinant of the relative firm-specific wage contract is the expected discounted sum of the rates of unemployment from the current period onward. The influence of unemployment on the labor-matching nominal wage is of a negative sign. A positive unemployment rate means that households wish to work more bundles of labor than the actual number of bundles, which compels a lower nominal wage to satisfy the labor matching condition.

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[16]See appendix 1 for the proof. One alternative way to express (19) is

$$\pi_t^w = -\frac{\theta_p}{\theta_w(1-\alpha)}\pi_t^p - \frac{(1-\beta\eta)(1-\eta)}{\eta\theta_w} E_t \sum_{j=0}^{\infty} \beta^j u_{t+j},$$

which means that wage-inflation fluctuations are negatively related to current price inflation and also negatively influenced by the stream of current and expected future rates of unemployment.

3. Pricing and Inflation Dynamics with Firm-Specific Sticky Wages

What are the implications of firm-specific sticky wages on price setting? And what are the implications on price inflation as a result of putting together optimal prices with unchanged prices? This section investigates these questions and derives the Phillips curve for the variant of the New Keynesian model with firm-specific sticky wages (FSW model henceforth). As mentioned above, sticky prices, and the subordinate sticky wages, are jointly introduced by assuming a constant probability for optimal pricing as in Calvo (1983). Therefore, the firm-specific (subordinate) nominal wage (20) is taken into account to find the optimal price because both prices and wages can be simultaneously reset. Supposing that the i-th firm can price optimally in period t, the value of $P_t(i)$ is the one that maximizes conditional intertemporal profits:[17]

$$E_t^\eta \sum_{j=0}^{\infty} \Delta_{t,t+j} \eta^j \left[\left(\frac{P_t(i)}{P_{t+j}} \right)^{1-\theta_p} y_{t+j} - \frac{W_t(i)}{P_{t+j}} n_{t+j}^d(i) \right],$$

where the rational-expectations operator, E_t^η, is conditional to not being able to change the price and the nominal wage in future periods, and $\Delta_{t,t+j}$ is the stochastic discount factor.[18] The optimality condition for $P_t(i)$ yields

$$E_t^\eta \sum_{j=0}^{\infty} \Delta_{t,t+j} \eta^j \left[(1-\theta_P)(P_t(i))^{-\theta_p} (P_{t+j})^{\theta_P - 1} y_{t+j} \right. \\ \left. - \frac{W_t(i)}{P_{t+j}} \frac{\partial n_{t+j}^d(i)}{\partial y_{t+j}(i)} \frac{\partial y_{t+j}(i)}{\partial P_t(i)} \right] = 0. \tag{21}$$

[17]Notice that total income and labor costs both are expressed in aggregate output units. In addition, total income is obtained as the product of the relative price multiplied by the units of output. So, total income of period t is $\frac{P_t(i)}{P_t} y_t(i) = \frac{P_t(i)}{P_t} (\frac{P_t(i)}{P_t})^{-\theta_p} y_t(i) = (\frac{P_t(i)}{P_t})^{1-\theta_p} y_t(i)$.

[18]The discount factor consistent with the household's optimizing behavior described above is $\Delta_{t,t+j} = \beta^j \frac{\exp(\chi_{t+j}) c_{t+j}^{-\sigma}}{\exp(\chi_t) c_t^{-\sigma}}$, which in steady state is constant at β^j.

Meanwhile, the conditional Dixit-Stiglitz demand constraints in any $t+j$ period,

$$y_{t+j}(i) = \left(\frac{P_t(i)}{P_{t+j}}\right)^{-\theta_p} y_{t+j}, \tag{22}$$

imply that

$$\frac{\partial y_{t+j}(i)}{\partial P_t(i)} = -\theta_p (P_t(i))^{-\theta_p - 1} (P_{t+j})^{\theta_P} y_{t+j}. \tag{23}$$

Inserting (23) into (21) and solving out for the optimal price $P_t(i)$, we obtain

$$P_t(i) = \frac{\theta_P}{\theta_P - 1} \frac{E_t^\eta \sum_{j=0}^{\infty} \Delta_{t,t+j} \eta^j [\psi_{t+j}(i)(P_{t+j})^{\theta_P} y_{t+j}]}{E_t^\eta \sum_{j=0}^{\infty} \Delta_{t,t+j} \eta^j [(P_{t+j})^{\theta_P - 1} y_{t+j}]}, \tag{24}$$

where $\psi_{t+j}(i) = \frac{W_t(i)}{P_{t+j}} \frac{\partial n_{t+j}^d(i)}{\partial y_{t+j}(i)}$ is the real marginal cost in period $t+j$ subject to the lack of optimal pricing and wage adjustments from period t through period $t+j$. Log-linearizing (24) yields

$$\widehat{P}_t(i) = (1 - \beta\eta) E_t^\eta \sum_{j=0}^{\infty} \beta^j \eta^j \big(\widehat{P}_{t+j} + \widehat{\psi}_{t+j}(i)\big). \tag{25}$$

The next task is to find an expression for $\widehat{P}_t(i)$ that only depends on aggregate variables so that we can derive a price-inflation equation. The conditional expectation of the log of the firm-specific real marginal cost that appears in (25) can be decomposed as follows:

$$E_t^\eta \widehat{\psi}_{t+j}(i) = \big(\widehat{W}_t(i) - E_t \widehat{P}_{t+j}\big) - E_t^\eta \widehat{mpl}_{t+j}(i), \tag{26}$$

where $\widehat{mpl}_{t+j}(i)$ is the log of the firm-specific marginal product of labor in $t+j$. It should be noticed that $E_t^\eta \widehat{\psi}_{t+j}(i)$ depends on the log of the nominal wage subordinated to the optimal price set in period t, $\widehat{W}_t(i)$. Recalling the production function (10), and the conditional Dixit-Stiglitz demand constraint (22), we can also express $E_t^\eta \widehat{mpl}_{t+j}(i)$ as a function of the optimal price in period t:

$$\begin{aligned} E_t^\eta \widehat{mpl}_{t+j}(i) = -\frac{\alpha}{1-\alpha} E_t^\eta \widehat{y}_{t+j}(i) = \frac{\theta_p \alpha}{1-\alpha} \big(\widehat{P}_t(i) - E_t \widehat{P}_{t+j}\big) \\ + E_t \widehat{mpl}_{t+j}, \end{aligned}$$

which can be substituted in (26) to yield

$$E_t^\eta \widehat{\psi}_{t+j}(i) = \left(\widehat{W}_t(i) - E_t \widehat{P}_{t+j}\right) - \frac{\theta_p \alpha}{1-\alpha}\left(\widehat{P}_t(i) - E_t \widehat{P}_{t+j}\right) - E_t \widehat{mpl}_{t+j}.$$

We can do some algebra to rewrite the last expression in the following way:[19]

$$\begin{aligned} E_t^\eta \widehat{\psi}_{t+j}(i) = E_t \widehat{\psi}_{t+j} &+ \left(\widehat{W}_t(i) - \widehat{W}_t - E_t \sum_{k=1}^{j} \pi_{t+k}^w\right) \\ &- \frac{\theta_p \alpha}{1-\alpha}\left(\widehat{P}_t(i) - \widehat{P}_t - \sum_{k=1}^{j} \pi_{t+k}^p\right), \end{aligned} \tag{27}$$

where it should be noticed that $\widehat{\psi}_{t+j}$ denotes the log of the aggregate real marginal cost $\widehat{\psi}_{t+j} = (\widehat{W}_{t+j} - \widehat{P}_{t+j}) - \widehat{mpl}_{t+j}$. The relative nominal wage in period t, $\widehat{W}_t(i) - \widehat{W}_t$, is given by equation (20), derived in the previous section. That result can be used in (27) to reach

$$\begin{aligned} \widehat{\psi}_{t+j}(i) = E_t \widehat{\psi}_{t+j} &- \frac{\theta_p(\alpha + \theta_w^{-1})}{1-\alpha}\left(\widehat{P}_t(i) - \widehat{P}_t\right) - \frac{(1-\beta\eta)}{\theta_w} E_t \sum_{j=0}^{\infty} \beta^j u_{t+j} \\ &+ E_t \sum_{k=1}^{j} \left(\frac{\theta_p \alpha}{1-\alpha}\pi_{t+k} - \pi_{t+k}^w\right), \end{aligned}$$

which can be substituted in (25) to obtain a value for $\widehat{P}_t(i) - \widehat{P}_t$ that only depends on aggregate variables:

$$\begin{aligned} \left(1 + \frac{\theta_p(\alpha + \theta_w^{-1})}{1-\alpha}\right)\left(\widehat{P}_t(i) - \widehat{P}_t\right) &= (1-\beta\eta) E_t \sum_{j=0}^{\infty} \beta^j \eta^j \widehat{\psi}_{t+j} \\ - \frac{(1-\beta\eta)}{\theta_w} E_t \sum_{j=0}^{\infty} \beta^j u_{t+j} &+ E_t \sum_{j=1}^{\infty} \beta^j \eta^j \left(\left(1 + \frac{\theta_p \alpha}{1-\alpha}\right)\pi_{t+j}^p - \pi_{t+j}^w\right). \end{aligned} \tag{28}$$

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[19] First, both $\widehat{W}_{t+j} - \widehat{W}_{t+j}$ and $\widehat{P}_{t+j} - \widehat{P}_{t+j}$ are inserted on the right-hand side of the equation and, secondly, $\widehat{W}_{t+j} = \widehat{W}_t + \sum_{k=1}^{j} \pi_{t+k}^w$ and $\widehat{P}_{t+j} = \widehat{P}_t + \sum_{k=1}^{j} \pi_{t+k}^p$ are used from the definitions of wage and price inflation.

The terms π^w_{t+j} can be replaced by those obtained when rewriting the expression that appears in footnote (16) for any $t+j$ period. Such substitutions in (28) lead to the following equation:

$$\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)\left(\widehat{P}_t(i)-\widehat{P}_t\right)=(1-\beta\eta)E_t\sum_{j=0}^{\infty}\beta^j\eta^j\widehat{\psi}_{t+j}$$
$$-\frac{1-\beta\eta}{\theta_w}E_t\sum_{j=0}^{\infty}\beta^j u_{t+j}+E_t\sum_{j=1}^{\infty}\beta^j\eta^j\left(\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)\pi^p_{t+j}\right.$$
$$\left.+\frac{(1-\eta)(1-\beta\eta)}{\eta\theta_w}\sum_{k=0}^{\infty}\beta^k u_{t+j+k}\right),$$

where the terms involving unemployment can be rearranged to obtain

$$\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)\left(\widehat{P}_t(i)-\widehat{P}_t\right)=(1-\beta\eta)E_t\sum_{j=0}^{\infty}\beta^j\eta^j\left(\widehat{\psi}_{t+j}-\frac{1}{\theta_w}u_{t+j}\right)$$
$$+E_t\sum_{j=1}^{\infty}\beta^j\eta^j\left(\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)\pi^p_{t+j}\right). \tag{29}$$

By combining (29) and (17), we can build a dynamic equation for $\pi^p_t-\beta\eta E_t\pi^p_{t+1}$ that, after simplifying terms, results in this price-inflation equation for the FSW model:[20]

$$\pi^p_t=\beta E_t\pi^p_{t+1}+\frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)}(\widehat{\psi}_t-\frac{1}{\theta_w}u_t). \tag{30}$$

The dynamic behavior of price inflation in (30) is purely forward looking and resembles quite closely the so-called New Keynesian Phillips curve with flexible wages (Sbordone 2002; Walsh 2003, chap. 5; Woodford 2003, chap. 3) because price inflation depends on the expected future rate of inflation and on the current aggregate

[20] See appendix 2 for the proof.

real marginal costs. However, the introduction of sticky wages set by demand-constrained firms makes the unemployment rate enter (30) with a negative impact on price inflation. The economic intuition behind this influence relies on the connection between prices and wages with firm-specific wage setting. A positive unemployment rate lowers nominal wages (as discussed in section 2), and the subsequent fall in the firm-specific real marginal cost has a negative influence on the rate of price inflation via optimal price resetting.

4. Two Variants for a Sticky-Wage New Keynesian Model

The basic New Keynesian model is built upon three elements: (i) an optimizing IS curve that describes a negative relationship between output and the real interest rate, (ii) a New Keynesian Phillips curve obtained from the aggregation of slowly adjusted prices set by profit-maximizing firms, and (iii) a monetary policy rule that determines short-run changes in the nominal interest rate (McCallum 2001; Walsh 2003, chap. 5). The presence of wage stickiness requires the inclusion of additional equations on the supply side for wage inflation, real marginal costs, or labor productivity as in the EHL (2000) model. Now we investigate the qualitative implications of the firm-specific wage-setting behavior described above in comparison to the common practice of having household-specific sticky wages.[21] Therefore, the analysis compares the structures of the EHL and FSW models.

Firstly, the common parts of the EHL and FSW models are introduced. Following McCallum and Nelson (1999), the IS curve can be obtained from the household's optimizing program described in section 2. The first-order conditions on consumption and bonds can be combined to reach this consumption Euler equation:

$$\frac{\exp(\chi_t)c_t^{-\sigma}}{\beta E_t\big(\exp(\chi_{t+1})c_{t+1}^{-\sigma}\big)} = \frac{1+R_t}{1+E_t\pi_{t+1}^p},$$

[21] Casares (2007b) conducts a similar comparison in a flexible-price scenario.

where inserting the market-clearing equilibrium conditions, $c_t = y_t$ and $c_{t+1} = y_{t+1}$, log-linearizing the result, and recalling the AR(1) generating process for the preference shock yields

$$\widehat{y}_t = E_t\widehat{y}_{t+1} - \frac{1}{\sigma}(R_t - E_t\pi^p_{t+1} - (1-\rho_\chi)\chi_t). \tag{31}$$

The resulting equation (31) is the expectational IS curve that indicates how output fluctuations are forward looking and depend negatively on the real interest rate, $R_t - E_t\pi^p_{t+1}$, and positively on the consumption preference shock, χ_t.

For now, let us suppose that monetary policy is conducted by a central bank whose policy actions follow a Taylor-type monetary policy rule (Taylor 1993) with an interest-rate-smoothing component,

$$R_t = \mu_{\pi^p}\pi^p_t + \mu_{\widetilde{y}}(\widehat{y}_t - \widehat{\overline{y}}_t) + \mu_R R_{t-1}, \tag{32}$$

with μ_{π^p}, $\mu_{\widetilde{y}}$, and $\mu_R \geq 0$ and being numbers that satisfy the Taylor principle to avoid indeterminacy.[22] The output-gap term that appears in (32) is defined as the log-difference between current output and potential (natural-rate) output, $\widehat{y}_t - \widehat{\overline{y}}_t$. Current output is determined by demand conditions in a way depicted by the IS curve (31). Potential output is the amount that would have been produced in the economy if both prices and wages were fully flexible to adjust optimally every period. Dropping nominal rigidities ($\eta = 0.0$), one can find that potential output fluctuations are (exogenously) determined by the following equation:[23]

$$\left(\frac{\alpha+\gamma}{1-\alpha} + \sigma\right)\widehat{\overline{y}}_t = (1+\gamma)z_t + \chi_t. \tag{33}$$

[22] As a general result, determinacy is guaranteed when $\mu_{\pi^p} + \mu_R > 1$. See Woodford (2003, chap. 4) for more detailed discussions.

[23] If prices fully adjust every period, the FSW model collapses into a flexible-price, flexible-wage economy with no unemployment (a kind of RBC economy with imperfect competition and heterogeneous labor). All the firms would choose the same optimal price and the same subordinate nominal wage. Since all the contracts are reset every period, all the pairs of labor supply and labor demand across differentiated labor services are well matched and equal. In turn, the labor market clears in terms of bundles of labor services and the unemployment rate is zero.

Equations (31), (32), and (33) will be shared by the models with either household-specific (EHL model) or firm-specific (FSW model) sticky wages because the wage-setting behavior does not alter their computation. The distinct components of both models are discussed next, mainly regarding the driving forces for price-inflation and wage-inflation fluctuations.

4.1 Firm-Specific Sticky Wages (FSW Model)

The price- and wage-setting interactions described above served to derive equation (30), which governs inflation dynamics in the FSW model. Price inflation is purely forward looking and depends on both the real marginal cost and the rate of unemployment. For comparative purposes with the EHL model, (30) will be transformed into one equivalent expression. Prior to that, let us define the log of the real wage as $\widehat{w}_t = \widehat{W}_t - \widehat{P}_t$ and use it when log-linearizing equation (5) to determine the log of the supply of labor bundles, $\widehat{n}_t^s$, then insert it into equation (15) to obtain the unemployment rate as follows:

$$u_t = \widehat{n}_t^s - \widehat{n}_t = \frac{1}{\gamma}(\widehat{w}_t - \sigma\widehat{y}_t + \chi_t) - \widehat{n}_t.$$

Meanwhile, we have from the utility function (1) that the log of the labor-consumption marginal rate of substitution (MRS) is $\widehat{mrs}_t = \gamma\widehat{n}_t + \sigma\widehat{c}_t - \chi_t$, where inserting the goods market-clearing condition, $\widehat{c}_t = \widehat{y}_t$, and subtracting the log of the real wage result in the following gap between the MRS and the real wage:

$$\widehat{mrs}_t - \widehat{w}_t = \gamma\widehat{n}_t + \sigma\widehat{y}_t - \chi_t - \widehat{w}_t. \tag{34}$$

Interestingly, the FSW model implies a close relationship between u_t and $\widehat{mrs}_t - \widehat{w}_t$. Observing the last two equations, one can see that

$$\widehat{mrs}_t - \widehat{w}_t = -\gamma u_t, \tag{35}$$

which allows us to express the inflation equation (30) in the following manner:

$$\pi_t^p = \beta E_t \pi_{t+1}^p + \frac{(1-\eta)(1-\beta\eta)}{\eta\Big(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\Big)}\left(\frac{1}{\gamma\theta_w}(\widehat{mrs}_t - \widehat{w}_t) - (\widehat{mpl}_t - \widehat{w}_t)\right), \tag{36a}$$

where we also used $\widehat{\psi}_t = \widehat{w}_t - \widehat{mpl}_t$. In turn, the price-inflation dynamics of the FSW model embedded in (36a) are governed by the reaction to two gaps:[24]

(i) the MRS gap, $\widehat{mrs}_t - \widehat{w}_t$, the log-deviation between the marginal rate of substitution and the real wage

(ii) the productivity gap, $\widehat{mpl}_t - \widehat{w}_t$, the log-deviation between the marginal productivity of labor and the real wage

The MRS gap represents the increase in the log of the real wage required to equate the supply of labor bundles to their actual level of employment. The reaction of price inflation to the labor-supply wedge, $\widehat{mrs}_t - \widehat{w}_t$, is absent in the traditional New Keynesian Phillips curve but present in (36a). Thus, the FSW model brings in the MRS gap as another explanatory variable for inflation dynamics due to the combination of sticky prices with firm-specific sticky wages. When the marginal rate of substitution exceeds the real wage, the unemployment rate turns negative, $u_t < 0.0$, because households' supply of labor bundles falls below their actual amount of work. Such negative unemployment has a positive impact on the firm-specific nominal wage subordinated to the optimal price (as discussed in section 2). More costly wages increase real marginal costs, optimal prices are posted higher, and, after aggregation, price inflation will rise.

The productivity gap, $\widehat{mpl}_t - \widehat{w}_t$, enters the inflation equation (36a) with a negative sign to reflect the impact of real marginal costs (note that $\widehat{mpl}_t - \widehat{w}_t$ is the log of the real marginal cost with a minus sign in front). Thus, if labor productivity exceeds the real

[24] Here we are mimicking the interpretation that Walsh (2003, chap. 5) makes from the EHL model.

wage, the real marginal cost becomes negative, and the fraction of firms that are able to reset their prices will post a lower price. So, price inflation falls after a positive productivity gap.

Turning to wage-inflation dynamics in the FSW model, we can substitute the term $\pi_t^p - \beta E_t \pi_{t+1}^p$ implied by (36a) in the wage-inflation equation (19) to yield

$$\pi_t^w = \beta E_t \pi_{t+1}^w + \frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\alpha\theta_w+\frac{\theta_w(1-\alpha)}{\theta_p}\right)}\left(\frac{1+\alpha(\theta_p-1)}{\gamma\theta_p}(\widehat{mrs}_t-\widehat{w}_t)+(\widehat{mpl}_t-\widehat{w}_t)\right), \tag{37a}$$

where the unemployment rate was also replaced by its relationship to the MRS gap using equation (35). Both the productivity gap and the MRS gap also affect the rate of wage inflation in the FSW model with a positive influence (the productivity gap had a negative impact on price inflation). The firm-specific wage-setting procedure subordinated to the pricing behavior explains these relationships. Thus, a positive productivity gap, $\widehat{mpl}_t - \widehat{w}_t > 0.0$, implies a negative value for the log of real marginal costs, which would make firms lower optimal prices, increase their amount of output (via a Dixit-Stiglitz demand curve), and thus also increase their labor demand. The (subordinate) firm-specific nominal wage would be raised as necessary to match the increasing labor demand with labor supply. Higher nominal wages on the revised contracts would increase the rate of wage inflation. Concerning the MRS gap, when $\widehat{mrs}_t - \widehat{w}_t > 0$, households wish to work fewer bundles of labor than their current employment, and newly revised nominal-wage contracts will have to be of higher value to match labor supply and labor demand. The fraction of firms that can reset wages would post higher nominal values that on the aggregate would push upward the rate of wage inflation.

Three more equations are needed to close the FSW model (which will also be part of the EHL model). The production function (10) implies this log of the aggregate marginal product of labor:

$$\widehat{mpl}_t = \widehat{y}_t - \widehat{n}_t, \tag{38}$$

and this log of aggregate output:

$$\widehat{y}_t = (1-\alpha)(\widehat{n}_t + z_t), \tag{39}$$

where it should be noticed that labor demand becomes effective labor.[25] Concerning the real-wage dynamics, we can take the first difference on the definition of the log of the real wage, $\widehat{w}_t = \widehat{W}_t - \widehat{P}_t$, to obtain

$$\widehat{w}_t = \widehat{w}_{t-1} + \pi_t^w - \pi_t^p. \tag{40}$$

All in all, the FSW model comprises ten equations, (31)–(40), that may determine solution paths for the ten endogenous variables: π_t^p, π_t^w, $\widehat{w}_t$, $\widehat{mpl}_t$, $\widehat{u}_t$, $\widehat{mrs}_t$, $\widehat{y}_t$, $\widehat{\overline{y}}_t$, $\widehat{n}_t$, and R_t. The model has two predetermined variables ($\widehat{w}_{t-1}$ and R_{t-1}) and two exogenous variables (supply shocks shaping technology, z_t, and demand shocks shaping consumption preference, χ_t).

4.2 Household-Specific Sticky Wages (EHL Model)

Unlike the setup just described, the common practice for a sticky-wage specification in the New Keynesian framework is to let households decide on the nominal-wage contract as first assumed by EHL (2000).[26] They build a labor-market structure with heterogeneous types of labor services, each of them supplied by one differentiated household. Thus, there are household-specific nominal wages that are slowly adjusted with constant probability à la Calvo (1983). Households may be able to set the nominal wage, whereas the amount of labor supplied is labor-demand constraint. Firms employ bundles of labor obtained using a Dixit-Stiglitz aggregator that combines all types of labor services. Thus, firms can substitute between differentiated labor services with a constant elasticity. In turn, EHL (2000) derives the following forward-looking wage-inflation equation:

$$\pi_t^w = \beta E_t \pi_{t+1}^w + \frac{(1-\eta_w)(1-\beta\eta_w)}{\eta_w(1+\gamma\widetilde{\theta}_w)}(\widehat{mrs}_t - \widehat{w}_t). \tag{37b}$$

[25] When firm-specific price and wage contracts are not reoptimized, firms are bound to produce as many units of differentiated output as demanded, whereas households are bound to supply as many units of differentiated labor as required to produce that output demand. Labor demand determines the effective level of employment.

[26] Other recent papers with household-specific sticky wages are Amato and Laubach (2003), Smets and Wouters (2003), Christiano, Eichenbaum, and Evans (2005), and Casares (2007a).

The slope coefficient in (37b) depends on structural parameters such as the Calvo (1983) sticky-wage constant probability, η_w; the elasticity of the labor marginal disutility, γ; the firms' elasticity of substitution across differentiated labor services, $\widetilde{\theta}_w$; and the intertemporal discount parameter, β. The MRS gap is the only driving force on wage-inflation dynamics in the EHL model. The assumption of household-specific sticky wages leaves the wage-inflation fluctuations determined exclusively by variables related to the household sector. Put differently, no firm-related variable such as labor productivity enters the wage-inflation equation in the EHL model.

Similarly for the price-inflation equation, the EHL model does not include the MRS gap, $\widehat{mrs}_t - \widehat{w}_t$, because the price-setting and wage-setting procedures are separated (prices for the firms, wages for the households). When firms set prices, they just look at their real marginal costs and take the same economy-wide nominal wage as given in their pricing decision. In turn, the price-inflation equation of the EHL model can be written as follows:[27]

$$\pi_t^p = \beta E_t \pi_{t+1}^p - \frac{(1-\eta_P)(1-\beta\eta_P)}{\eta_p\left(1+\frac{\alpha\theta_p}{1-\alpha}\right)}(\widehat{mpl}_t - \widehat{w}_t). \tag{36b}$$

To summarize, table 1 reports the determinants of the dynamic behavior of both price and wage inflation in the FSW and EHL models. Productivity gaps, $\widehat{mpl}_t - \widehat{w}_t$, reduce price inflation in both sticky-wage setups, whereas they raise wage inflation only in the FSW model. On the other hand, MRS gaps, $\widehat{mrs}_t - \widehat{w}_t$, have a positive impact on wage inflation in both models and also a negative influence on price inflation in the FSW model.

The set of equations of the EHL model can be obtained by making three changes in the system (31)–(40) belonging to the FSW model. We first introduce (36b) instead of (36a) for the price-inflation dynamics. Secondly, (37b) enters the system, replacing

[27] See Sbordone (2002) for an explicit derivation. The price-inflation equation of the EHL (2000) paper has a slightly different slope coefficient because the real marginal cost is not firm specific in their model.

Table 1. Determinants of Price Inflation and Wage Inflation

Price-Inflation Equation		
	FSW Model, Eq. (36a)	**EHL Model, Eq. (36b)**
Productivity Gap, $\widehat{mpl}_t - \widehat{w}_t$	$(-)$	$(-)$
MRS Gap, $\widehat{mrs}_t - \widehat{w}_t$	$(+)$	0
Wage-Inflation Equation		
	FSW Model, Eq. (37a)	**EHL Model, Eq. (37b)**
Productivity Gap, $\widehat{mpl}_t - \widehat{w}_t$	$(+)$	0
MRS Gap, $\widehat{mrs}_t - \widehat{w}_t$	$(+)$	$(+)$

(37a) for wage-inflation dynamics. The third step would consist of eliminating equation (35) because there is no unemployment in the EHL model. These three variations would lead to a nine-equation system that provides solution paths for the nine endogenous variables: π_t^p, π_t^w, $\widehat{w}_t$, $\widehat{mpl}_t$, $\widehat{mrs}_t$, $\widehat{y}_t$, $\widehat{\overline{y}}_t$, $\widehat{n}_t$, and R_t. Predetermined variables and shocks are assumed to be identical in both sticky-wage setups.

4.3 Baseline Parameterization

In the next two sections, we carry out the business-cycle and monetary policy analysis in the EHL and FSW models. For such applied exercises, some numerical values of their structural parameters are required. Borrowing numbers from the baseline quarterly calibration used in EHL (2000), we set $\beta = 0.99$, $\sigma = 1.5$, $\gamma = 1.5$, $\alpha = 0.3$, $\theta_p = 4.0$, $\widetilde{\theta}_w = 0.4$, and $\eta_p = \eta_w = 0.75$ in the EHL model. These values assigned to β, σ, γ, α, and θ_p are also set in the FSW model. In the FSW model, a single Calvo probability, η, collects the level of price and wage stickiness since wage setting is subordinated to the pricing decision. Thus, in the FSW model, we set the same Calvo probability as in the EHL model, $\eta = 0.75$, which means that both prices and wages are reset optimally once per year.[28] The households' elasticity of substitution regarding the supply of differentiated labor services—exclusive from the FSW model—is set at $\theta_w = 4.0$ also to be equal to the elasticity of substitution of firms' demand for labor in the EHL model.[29] The interest rate monetary policy rule (32) is somehow different here compared with that in EHL (2000), and we assign, on empirical grounds, the Taylor (1993) original coefficients with a significant extent of interest rate smoothing, $\mu_R = 0.8$. Using the partial-adjustment mechanism for monetary policy proposed by Clarida, Galí, and Gertler (1998), the reaction coefficients to inflation deviations and the output gap become $\mu_{\pi^p} = 1.5(1 - 0.8) = 0.3$ and $\mu_{\widetilde{y}} = \frac{0.5}{4}(1 - 0.8) = 0.025$.

As for the stochastic elements, the standard deviations of the innovation of the shocks are chosen with a double criteria. First, total variability of output gives a standard deviation of output equal to 2 percent. Second, supply (technology) shocks account for 60 percent of that output variability in the long-run variance decomposition (100 periods ahead), whereas demand shocks explain the remaining 40 percent.[30] Serial correlation is set to be very high for technology shocks ($\rho_z = 0.95$) and moderately high for demand shocks ($\rho_\chi = 0.80$). Table 2 collects all the baseline numerical values of parameters used in both the FSW and EHL models.

Even though the FSW and EHL models share the same degree of frictions on price and wage setting ($\eta = 0.75$ in the FSW model and $\eta_p = \eta_w = 0.75$ in the EHL model), the slope coefficients in their price-inflation and wage-inflation equations are clearly different (see table 3). Thus, the price-inflation equation in the FSW model has a coefficient on the productivity gap lower than that in the EHL model (0.0207 versus 0.0316). Besides, the

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[28] Taylor (1999) reviews a survey of empirical papers to conclude that it can be realistic to assume the same price and wage stickiness in around one optimal adjustment per year.

[29] However, we must keep in mind that these elasticities of substitution have a distinct economic interpretation.

[30] The role of supply and demand shocks in the accounting of output business-cycle fluctuations is a matter of recent controversy. Smets and Wouters (2003, 2007) claim that supply-side shocks originate most output fluctuations in both the United States and the euro area, whereas Dufourt (2005) and Gordon (2005) find that demand shocks explain a fraction of output variability in the United States significantly higher than that due to supply shocks.

Table 2. Baseline Numerical Values of Parameters

FSW Model		EHL Model	
$\beta = 0.99$	$\eta = 0.75$	$\beta = 0.99$	$\eta_p = \eta_w = 0.75$
$\sigma = 1.50$	$\mu_{\pi^p} = 0.30$	$\sigma = 1.50$	$\mu_{\pi^p} = 0.30$
$\gamma = 1.50$	$\mu_{\widetilde{y}} = 0.025$	$\gamma = 1.50$	$\mu_{\widetilde{y}} = 0.025$
$\alpha = 0.30$	$\mu_R = 0.80$	$\alpha = 0.30$	$\mu_R = 0.80$
$\theta_p = 4.00$	$\theta_w = 4.00$	$\theta_p = 4.00$	$\widetilde{\theta}_w = 4.00$
$\rho_z = 0.95$	$\rho_\chi = 0.80$	$\rho_z = 0.95$	$\rho_\chi = 0.80$
$\sigma_{\varepsilon^z} = 1.05\%$	$\sigma_{\varepsilon^\chi} = 1.34\%$	$\sigma_{\varepsilon^z} = 0.98\%$	$\sigma_{\varepsilon^\chi} = 1.32\%$

Table 3. Slope Coefficients at Baseline Values of Parameters

	Price-Inflation Equation	
	FSW Model, Eq. (36a)	**EHL Model, Eq. (36b)**
For $\widehat{mpl}_t - \widehat{w}_t$	$\frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\frac{\theta_p\left(\alpha+\theta_w^{-1}\right)}{1-\alpha}\right)} = 0.0207$	$\frac{(1-\eta_P)(1-\beta\eta_P)}{\eta_p\left(1+\frac{\alpha\theta_p}{1-\alpha}\right)} = 0.0316$
For $\widehat{mrs}_t - \widehat{w}_t$	$\frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\frac{\theta_p\left(\alpha+\theta_w^{-1}\right)}{1-\alpha}\right)}\frac{1}{\gamma\theta_w} = 0.0035$	0.0
	Wage-Inflation Equation	
	FSW Model, Eq. (37a)	**EHL Model, Eq. (37b)**
For $\widehat{mpl}_t - \widehat{w}_t$	$\frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\alpha\theta_w+\frac{\theta_w(1-\alpha)}{\theta_p}\right)} = 0.0296$	0.0
For $\widehat{mrs}_t - \widehat{w}_t$	$\frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\alpha\theta_w+\frac{\theta_w(1-\alpha)}{\theta_p}\right)}\frac{1+\alpha(\theta_p-1)}{\gamma\theta_p} = 0.0094$	$\frac{(1-\eta_w)(1-\beta\eta_w)}{\eta_w(1+\gamma\widetilde{\theta}_w)} = 0.0123$

MRS gap has less influence than the productivity gap in price-inflation fluctuations of the FSW model because its coefficient is significantly smaller (0.0035). In the EHL model, there is no effect from the MRS gap on price inflation. Regarding wage-inflation dynamics, the slope coefficients are rather similar for the productivity gap under household-specific or firm-specific sticky wages (0.0123 in the EHL model and 0.0094 in the FSW model). However, wage inflation is more sensitive to the productivity gap than to the MRS gap in the FSW model because its slope coefficient is 0.0296 (more than three times higher). In the EHL model, there is no influence on wage-inflation dynamics coming from the productivity gap.

5. Business-Cycle Analysis

Impulse-response functions can be obtained from innovations in the supply (technology) shock, z_t, and the demand (IS) shock, χ_t.[31] The sizes of the innovations are normalized to one standard deviation (numbers provided in table 2) and are compared in both sticky-wage New Keynesian models. Responses are plotted in figure 1 (supply shock) and figure 2 (demand shock) in percent deviations from the steady-state values for output, the real wage, labor productivity, the marginal rate of substitution, and labor demand, whereas unemployment, price inflation, and wage inflation are directly displayed as level departures from the steady-state rates.

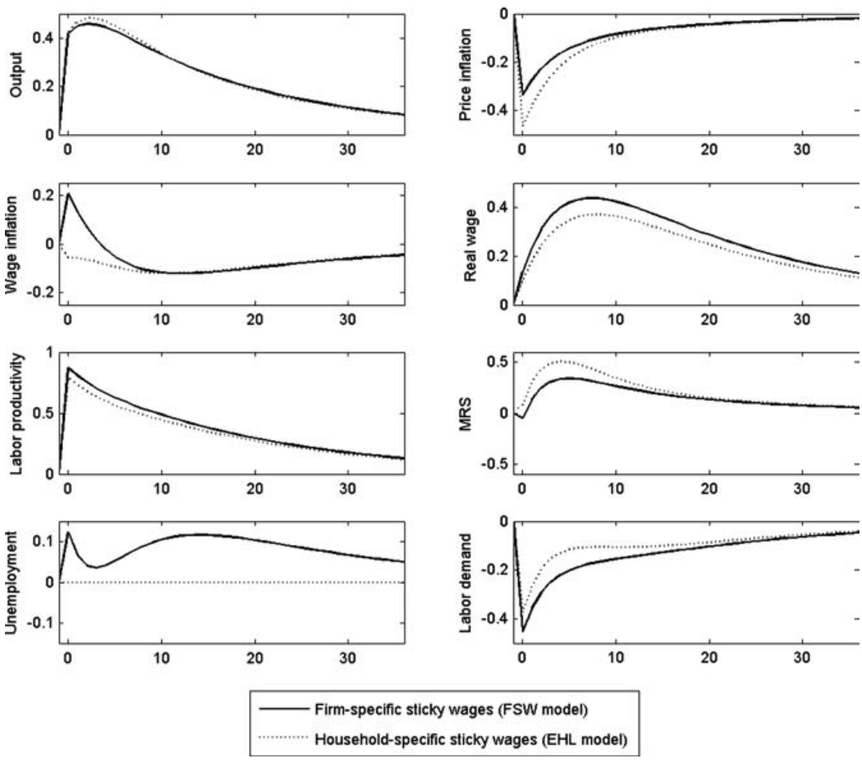
5.1 Supply (Technology) Shock

Figure 1 shows that both output and labor productivity respond to a technology shock with very similar long-lasting rises in the FSW and EHL models. By contrast, wage inflation has a distinctive reaction depending on the wage-setting behavior of the model. When households set nominal wages (EHL model), the model predicts a drop in wage inflation because new wage contracts are set downward. The reason for this behavior is that wage inflation only reacts to the MRS gap (see equation 37b). This gap turns out to be negative due to the initial drop in the MRS and the subsequent increase in the real wage.

If wages are subordinated to the pricing decision of firms (FSW model), wage inflation reacts very differently. In that sticky-wage specification, the change of wage inflation is the result of combining

[31] Even though the demand shock is a consumption-preference shock, we could observe analogous effects from other demand-side shocks such as a fiscal policy shock, an investment-related shock, or a monetary policy shock. Actually, an interest rate shock entering the Taylor-type monetary policy rule (32) would turn absolutely equivalent to a contractionary (negative-signed) demand shock entering the IS curve (31).

Figure 1. One-Standard-Deviation Supply (Technology) Shock: Impulse-Response Functions in the New Keynesian Model with Alternative Sticky-Wage Specifications



the influence of both the productivity gap and the MRS gap. With the technological improvement that brings the shock, the productivity gap becomes clearly positive and outweights the influence of the MRS gap. In turn, wage inflation rises.

The rate of price inflation and the real wage react to the technology shock moving in the same direction in both sticky-wage setups. However, the real wage increases more strongly in the FSW model, whereas price inflation has a more significant drop in the EHL model. The response of the real wage is higher in the FSW model because wage inflation rises there, while it falls in the EHL model. As for the price-inflation reaction, the slope coefficient for the productivity gap is lower in the FSW model (see table 3), as a consequence of the price/wage connections with firm-specific sticky wages. Subsequently, the inflation drop is greater in the EHL model.

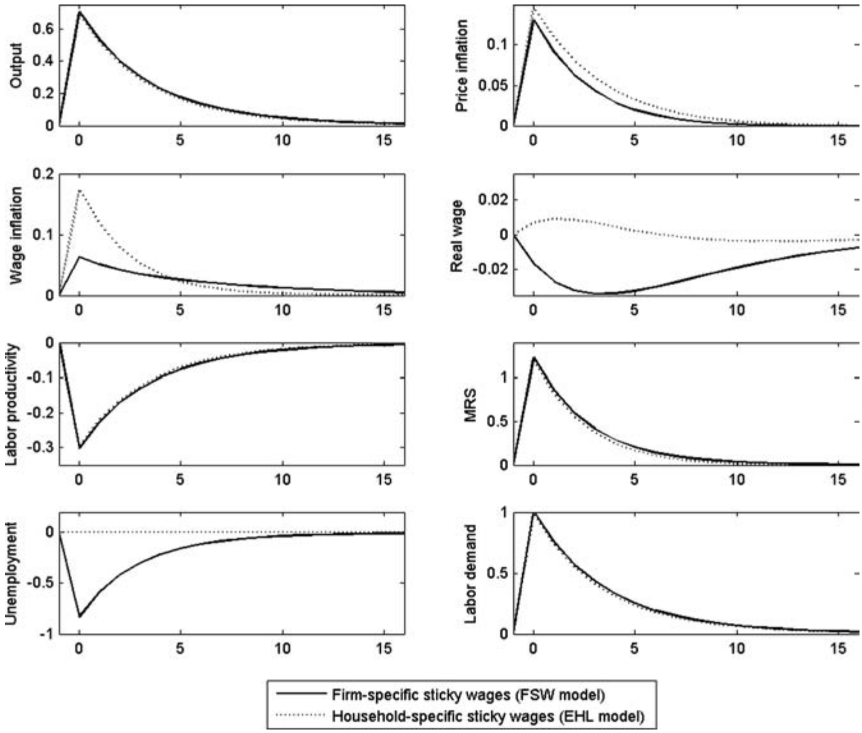
Finally, the rate of unemployment rises in the FSW model, whereas it remains at zero by construction in the EHL model. The unemployment reaction observed in the FSW model is not quantitatively large (the peak increase is approximately one-fourth of the output change). The decline in labor demand that results from the productivity hike explains why unemployment rises. Concretely, the types of labor services that do not have their wage contract revised suffer from a mismatch between labor supply and demand. Their labor demand falls below labor supply because their relative prices are rising due to the lack of price adjustments. Thus, wage stickiness in the FSW model predicts a higher rate of unemployment in response to an expansionary technology shock.

5.2 Demand (IS) Shock

A consumption-preference shock leads to an increase in the households' demand for consumption bundles that expands the IS curve (31) to higher levels of demand-driven output. Figure 2 shows the effects of this expansionary demand shock. At first, output and price inflation rise while (labor) productivity falls under both sticky-wage specifications. The cases of firm-specific or household-specific sticky wages are distinguishable in the reactions of wage inflation, the real wage, and unemployment. Even though wage inflation rises in both sticky-wage setups, the FSW model reports a substantially smaller increase, approximately one-third of that reported in the EHL model (see figure 2). This difference is obtained because in the FSW model wage inflation reacts to the productivity gap, $\widehat{mpl}_t - \widehat{w}_t$, which happens to be negative due to the fall in productivity. In turn, the impact of a positive MRS gap, $\widehat{mrs}_t - \widehat{w}_t > 0$, is partially compensated by a decreasing productivity gap, $\widehat{mpl}_t - \widehat{w}_t < 0$. In the EHL model, there is no influence of productivity on wages, which brings about a stronger reaction of wage inflation.

Meanwhile, price inflation rises in both sticky-wage models due to lower productivity and higher real marginal costs. Quantitatively, the response of price inflation is just slightly higher in the EHL

Figure 2. One-Standard-Deviation Demand (IS) Shock: Impulse-Response Functions in the New Keynesian Model with Alternative Sticky-Wage Specifications



model.[32] As for the real wage, its reaction is obtained when making the difference between the responses of wage inflation and price inflation. In the FSW model, the real wage drops because wage inflation increases to a smaller extent than price inflation. On the contrary, the EHL model reports an increase of wage inflation sufficiently large to produce a higher real wage despite the rise of price inflation.

[32]The responses of price inflation turn out to be nearly identical despite the differences in the driving forces of inflation between the FSW and the EHL model. Thus, the lower slope coefficient in reaction to the productivity gap in the FSW model is almost neutralized by the inflationary effect of the MRS gap that the EHL model does not capture (see table 3 for the numerical values of the slope coefficients).

Hence, the FSW model implies that the real wage would be countercyclical in the presence of a demand shock (higher output, lower real wage), while it reacts in a procyclical fashion in the EHL model (higher output, higher real wage).

Figure 2 also shows that the rate of unemployment falls below its steady-state value in the model with firm-specific sticky wages. Firms demand more labor to produce the additional units of output resulting from the consumption expansion. Since 75 percent of the wage contracts cannot be revised, households have to work longer than desired on those labor services whose contracts are not adjusted. The excess of labor demand over labor supply in aggregate terms represents the reduction of the unemployment rate below its steady-state value.

Summarizing, the impulse-response analysis of the New Keynesian model under different wage-setting behavior confirms a distinctive behavior of the supply side of the model (wage inflation, price inflation, the real wage, and unemployment) in the presence of supply and demand shocks. Wage inflation responds to fluctuations in the MRS if households set nominal wages (EHL model), whereas it reacts to those and also to changes in labor productivity if firms are wage setters (FSW model). In turn, the wage-inflation response to a technology shock is of a different sign. The real wage is procyclical after both shocks in the EHL model, whereas it is procyclical after a supply shock and countercyclical after a demand shock in the FSW model. Regarding inflation, we have observed that the responses are slightly smaller with firm-specific wages. Finally, unemployment rises with a supply shock and falls with a demand shock in the FSW model and has no reaction in the EHL model.

5.3 The Real-Wage Business Cycle and the Sumner-Silver Hypothesis

Sumner and Silver (1989) suggest with an empirical paper that the cyclicality of real wages in the United States depends on the cause of the cycle: if the business cycle is driven by supply shocks, the real wage is strongly procyclical, whereas if demand shocks originate output fluctuations, the real wage becomes clearly anticyclical. Their result provides a convincing empirical explanation of why the correlation between business-cycle fluctuations of output and the real wage is positive and weak in the U.S. economy (Abraham and Haltiwanger 1995). The sign of the correlation varies with the sample period, as the current business cycle is caused by either supply shocks (positive correlation) or demand shocks (negative correlation).

As discussed above, the real wage is procyclical after a technology shock and responds anticyclically in reaction to demand shocks in the FSW model, which replicates the Sumner-Silver empirical findings.[33] By contrast, the reactions of the real wage in the EHL model are procyclical to both supply and demand shocks, which implies that the Sumner-Silver hypothesis cannot be validated and the real wage would turn strongly procyclical.[34]

Table 4 reports the coefficients of correlation between the real wage and output obtained at the baseline price/wage stickiness, $\eta = 0.75$ in the FSW model and $\eta_p = \eta_w = 0.75$ in the EHL model. The real-wage correlations with output are computed in reactions observed to exclusively supply or demand shocks. If households act as wage setters (EHL model), the real wage is highly procyclical with supply shocks, with a coefficient of linear correlation $\rho(\widehat{w}_t, \widehat{y}_t) = 0.92$, and it also shows a clear procyclical behavior with demand shocks, $\rho(\widehat{w}_t, \widehat{y}_t) = 0.71$. The latter fails to be consistent with the Sumner-Silver empirical hypothesis. However, the FSW

Table 4. Real-Wage Correlation with Output at Baseline Price/Wage Stickiness

	FSW Model with $\boldsymbol{\eta = 0.75}$	**EHL Model with $\boldsymbol{\eta_p = \eta_w = 0.75}$**
Supply Shocks	0.94	0.92
Demand Shocks	−0.72	0.71

[33] Bénassy (1995) shows that the cyclicality of the real wage in an optimizing model with flexible prices and predetermined wages is also consistent with the Sumner-Silver hypothesis.

[34] Of course, this result might change if we had other sources of variability (shocks) in the model. Nevertheless, monetary (interest rate) shocks have the same impact as a contractionary demand shock.

model provides real-wage correlations consistent with the Sumner-Silver empirical hypothesis. When supply shocks hit the economy, the real wage is strongly procyclical, $\rho(\widehat{w}_t, \widehat{y}_t) = 0.94$, while the real wage turns clearly anticyclical if demand shocks drive the business cycle, $\rho(\widehat{w}_t, \widehat{y}_t) = -0.72$.

5.3.1 Sensitivity Analysis

Next, we will examine the robustness of the real-wage cyclicality to changes in the level of nominal rigidities on price/wage setting. The analysis is somehow different for each sticky-wage specification at hand. The FSW model has a single Calvo probability for both price and wage stickiness (η). The value of η will be adjusted to consider cases in which the average length of price/wage contracts runs from two quarters ($\eta = 0.5$) to ten quarters ($\eta = 0.9$). The EHL model with household-specific sticky wages features two Calvo probabilities—one for price stickiness affecting firms (η_p) and another one for wage stickiness affecting households (η_w). The sensitivity analysis consists then on moving either η_p or η_w from 0.5 to 0.9 while leaving the other unchanged at 0.75.

Figure 3 displays the results of this sensitivity analysis. The coefficient of correlation between output and the real wage in the presence of supply shocks is always positive and close to 1 at any level of price/wage rigidities in both sticky-wage models (see the plot on the left-hand side of figure 3). Consequently, these correlation coefficients lie on the shaded area that would represent the Sumner-Silver hypothesis.[35] With demand shocks, the real wage is always anticyclical in the FSW model, with negative coefficients of correlation with output that enter the Sumner-Silver area in the plot on the right-hand side of figure 3. Numerical values for the limit cases $\eta = 0.5$ and $\eta = 0.90$ are reported in table 5.

The real-wage cyclicality after a demand shock in the EHL model depends upon the relative price/wage stickiness as shown in figure 3. If the wage-stickiness parameter is at $\eta_w = 0.80$ or higher values, with $\eta_p = 0.75$, wage inflation would barely increase after the shocks and the real-wage response would be more affected by the rise of

[35] Arbitrarily, it is assumed that a coefficient of correlation greater than 0.5 in absolute value represents strong linear dependence.

Figure 3. Real-Wage Cyclicality and Nominal Rigidities: A Robustness Test of the Sumner-Silver Hypothesis in the FSW and EHL Sticky-Wage Models

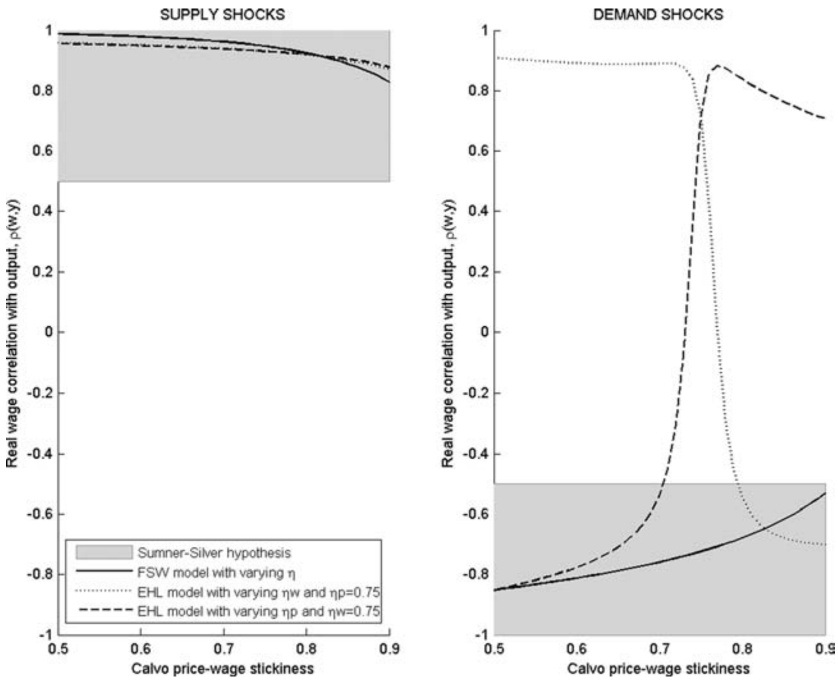


Table 5. Real-Wage Correlation with Output at Various Levels of Price/Wage Stickiness

	FSW Model	EHL Model
Supply Shocks	$\eta = 0.50 \rightarrow 0.98$ $\eta = 0.90 \rightarrow 0.83$	$\eta_p = 0.50$ and $\eta_w = 0.75 \rightarrow 0.95$ $\eta_p = 0.90$ and $\eta_w = 0.75 \rightarrow 0.88$ $\eta_p = 0.75$ and $\eta_w = 0.50 \rightarrow 0.96$ $\eta_p = 0.75$ and $\eta_w = 0.90 \rightarrow 0.87$
Demand Shocks	$\eta = 0.50 \rightarrow -0.85$ $\eta = 0.90 \rightarrow -0.53$	$\eta_p = 0.50$ and $\eta_w = 0.75 \rightarrow -0.85$ $\eta_p = 0.90$ and $\eta_w = 0.75 \rightarrow 0.71$ $\eta_p = 0.75$ and $\eta_w = 0.50 \rightarrow 0.91$ $\eta_p = 0.75$ and $\eta_w = 0.90 \rightarrow -0.70$

price inflation than by that of wage inflation. It results in a real-wage drop and therefore a negative correlation between the real wage and output (see the plot on the right-hand side of figure 3). Table 5 shows that the case when $\eta_p = 0.75$ and $\eta_w = 0.90$ in the EHL model with demand shocks leads to the negative correlation $\rho(\widehat{w}_t, \widehat{y}_t) = -0.70$.

A second possibility is to lower price stickiness. The right-side plot of figure 3 also shows that the coefficient of correlation between the real wage and output with demand shocks turns negative and enters the Sumner-Silver area when η_p falls below 0.70. Thus, table 4 reports significantly countercyclical real wages with demand shocks, $\rho(\widehat{w}_t, \widehat{y}_t) = -0.85$, when setting $\eta_p = 0.50$ and $\eta_w = 0.75$ in the EHL model.

In review, the FSW model satisfies the Sumner-Silver hypothesis at any of the levels of price/wage stickiness examined here. In the EHL model, by contrast, only the calibration with a degree of wage stickiness more persistent than price stickiness is consistent with the Sumner-Silver hypothesis.

6. Monetary Policy Analysis

This section deals with issues related to monetary policy. In particular, we will look for answers to the following two questions:

(i) What are the implications for optimal monetary policy design of having either household-specific or firm-specific sticky wages in the New Keynesian model?

(ii) Can we approximate optimal monetary policy fairly enough using a Taylor-type instrument rule (32) in both sticky-wage cases? If so, what values for the reaction coefficients are required to pursue optimal policy?

So far, monetary policy has followed (32) with a numerical specification for its policy coefficients μ_{π^p}, $\mu_{\widetilde{y}}$, and μ_R that conveys the Taylor (1993) original prescription together with a significant degree of interest rate inertia. Now, we can examine the stabilizing properties of that baseline specification of (32) by comparing it with optimal monetary policy. Furthermore, we will search the *optimized* coefficients for (32) as the triplet that best approximates optimal policy. To begin with, we follow Woodford (2003, chap. 6) and Giannoni and Woodford (2004) to derive the model-based second-order approximation of welfare losses obtained from the utility function of the model. In the FSW model, this welfare-theoretic instantaneous loss function is

$$L_t = \left(\pi_t^p\right)^2 + \lambda(\widetilde{y}_t - \widetilde{y}^*)^2, \tag{41}$$

where $\widetilde{y}_t = \widehat{y}_t - \widehat{\overline{y}}_t$ is the output gap, $\widetilde{y}^* = \frac{1}{\theta_p(\frac{\alpha+\gamma}{1-\alpha}+\sigma)}$ is the steady-state efficient output gap, and the weight on output-gap variability is $\lambda = \frac{(1-\eta)(1-\beta\eta)(\frac{\alpha+\gamma}{1-\alpha}+\sigma)}{\eta(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha})\theta_p}$ (see appendix 3 for its derivation). Therefore, optimal monetary policy targets the variability of price inflation (around its zero steady-state rate) and the variability of the output gap around its steady-state efficient level. This is the same policy recommendation assessed by Woodford (2003, chap. 6) for a New Keynesian model of Calvo-style staggered pricing, heterogeneous labor, and flexible wages. Even though wages are also sticky in the FSW model, the only source of nominal frictions is the Calvo-type probability, η, attached firsthand to the price-setting decision of firms and subsequently to wage adjustments because they are subordinated to optimal prices. In other words, sticky wages and sticky prices are part of the same nominal friction. The role of firm-specific sticky wages in the central-bank loss function is embedded at the value of λ in (41) through the elasticity parameter θ_w, which is absent in models with flexible prices or household-specific sticky wages.[36] Besides, the FSW model permits a trade-off between variabilities of price inflation and the output gap regardless of nominal shocks (documented below), which was not possible in standard models with sticky prices (Taylor 1979; Clarida, Galí, and Gertler 1999).

The welfare-theoretic optimal monetary policy can be obtained in the FSW model by finding the targeting rule that minimizes the expected intertemporal welfare losses, $E_t \sum_{j=0}^{\infty} \beta^j L_{t+j}$, subject to a

[36] In a model with heterogeneous labor, fully flexible wages, and staggered prices á la Calvo, the central bank loss function would be (41) with a slightly different $\lambda = \frac{(1-\eta)(1-\beta\eta)(\frac{\alpha+\gamma}{1-\alpha}+\sigma)}{\eta(1+\frac{\theta_p(\alpha+\gamma)}{1-\alpha})\theta_p}$ (Woodford 2003, chaps. 6 and 8).

reduced set of the structural equations of the model.[37] Such an optimizing program and its first-order conditions are shown in appendix 4. For policy simulations, the baseline numerical parameterization displayed in table 2 can be used to imply the value of $\lambda = 0.021$. This stabilizing policy preference can be used to optimize the policy coefficients for the Taylor-type rule (32). In particular, we search values of the triplet μ_{π^p}, $\mu_{\widetilde{y}}$, and μ_R that minimize the (long-run) unconditional expectation of $\sum_{j=0}^{\infty} \beta^j L_{t+j}$ in the FSW model.[38] It leads to

$$\mu^*_{\pi^p} = 4.09,\ \mu^*_{\widetilde{y}} = 1.17,\ \text{and}\ \mu^*_R = 1.54,$$

which indicate that the nominal interest rate should strongly respond to changes in price inflation and in a more moderate way to the output gap and the previous nominal interest rate. The optimized coefficients are significantly higher than those proposed in Taylor (1993) and used in our previous calibration.

Table 6 examines the stabilizing performance of three alternative monetary policy rules in the FSW model: (i) the (optimal) welfare-theoretic targeting rule with $\lambda = 0.021$; (ii) the baseline Taylor-type rule (32) with $\mu_{\pi^p} = 0.3$, $\mu_{\widetilde{y}} = 0.025$, and $\mu_R = 0.8$; and (iii) the optimized Taylor-type rule (32) with $\mu^*_{\pi^p} = 4.09$, $\mu^*_{\widetilde{y}} = 1.17$, and $\mu^*_R = 1.54$. One can see that the standard deviations of both price inflation and the output gap are much lower when applying the optimal policy compared with the baseline instrument rule. They are cut to approximately one-fourth of their values—from 0.68 percent to 0.16 percent in the case of price inflation, and from 0.67 percent to 0.19 percent in the output gap. However, both wage inflation and the nominal interest rate report a somewhat higher standard deviation with the welfare-theoretic targeting rule because optimal policy does not contemplate any concern on their variabilities (see table 6 for the numbers). When switching from the baseline to the optimized coefficients in (32), the standard deviation of price inflation falls to 0.18 percent and that

[37]The optimal monetary policy analysis based on the utility function is a subproduct of the targeting-rules approach introduced by Svensson (1999) and Woodford (1999).

[38]This same criterion has been used for monetary policy analysis by Levin and Williams (2003), Adalid et al. (2005), and Casares (2007a).

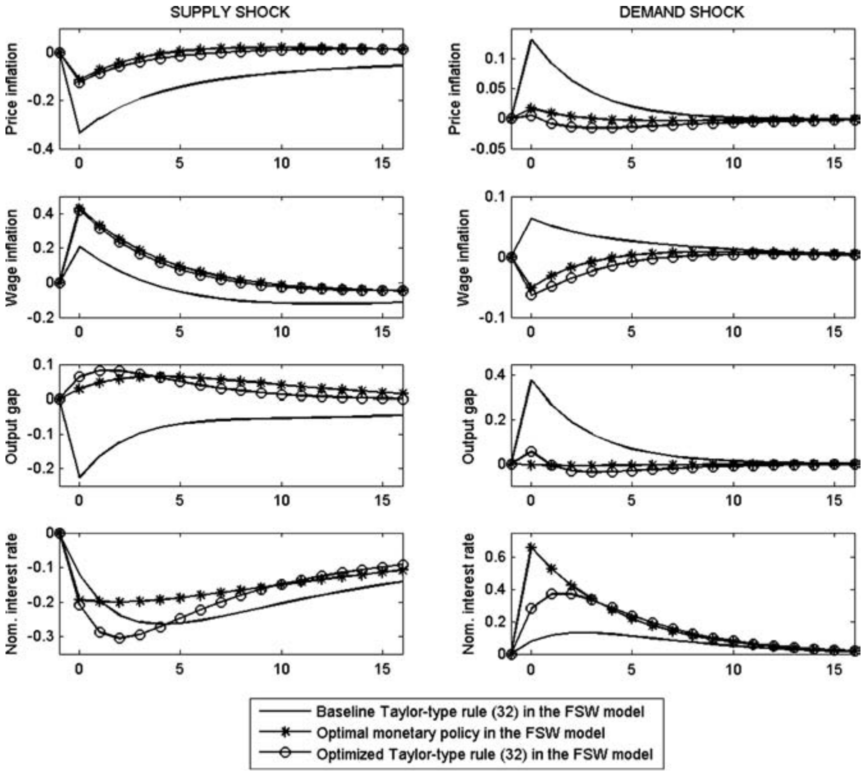
Table 6. Performance of Monetary Policy Rules

	Std. Deviations (%, Annualized)				Loss Ratio
FSW Model	π^p	π^w	$\widetilde{y}$	R	L/L^*
Welfare-Theoretic Targeting Rule (Optimal) ($\lambda = 0.021$)	0.16	0.69	0.19	1.33	1.00
Baseline Taylor-Type Rule (32) ($\mu_{\pi^p} = 0.30$, $\mu_{\widetilde{y}} = 0.025$, $\mu_R = 0.80$)	0.68	0.60	0.67	1.01	16.64
Optimized Taylor-Type Rule (32) ($\mu^*_{\pi^p} = 4.09$, $\mu^*_{\widetilde{y}} = 1.17$, $\mu^*_R = 1.54$)	0.18	0.65	0.20	1.21	1.29
EHL Model	π^p	π^w	$\widetilde{y}$	R	$\mathcal{L}/\mathcal{L}^*$
Welfare-Theoretic Targeting Rule (Optimal) ($\lambda_{\pi^p} = 0.357$, $\lambda_{\widetilde{y}} = 0.012$)	0.50	0.20	0.03	1.40	1.00
Baseline Taylor-Type Rule (32) ($\mu_{\pi^p} = 0.30$, $\mu_{\widetilde{y}} = 0.025$, $\mu_R = 0.80$)	0.89	0.50	0.57	1.16	4.96
Optimized Taylor-Type Rule (32) ($\mu^*_{\pi^p} = 39.46$, $\mu^*_{\widetilde{y}} = 100.0$, $\mu^*_R = 0.72$)	0.50	0.22	0.05	1.49	1.04

of the output gap to 0.20 percent, which are values only slightly higher than the numbers obtained under the optimal policy. In overall terms, the ratio of the unconditional loss value under the Taylor-type rule (32) divided by that loss under the optimal policy (denoted as L/L^* in table 6) is more than 16 with the baseline coefficients in (32) and gets reduced to only 1.29 with the optimized coefficients in (32). Therefore, it could be said that the stabilizing performance of the instrument rule (32) with the baseline coefficients is quite poor, whereas replacing those with optimized coefficients provides a very good approximation to optimal policy.

Figure 4 shows how the responses of price inflation and the output gap to supply and demand shocks in the FSW model are

Figure 4. Monetary Policy Analysis in the FSW Model: Responses to a Supply Shock (Left) and to a Demand Shock (Right) under Different Monetary Policy Rules



quantitatively much smaller under the optimal welfare-theoretic policy compared with the baseline specification of (32). By contrast, the use of the optimized coefficients in (32) allows that Taylor-type rule to mimic fairly well the responses of price inflation and the output gap obtained with the optimal policy, which confirms its good stabilizing performance. Wage inflation responds more aggressively under the optimal policy (and the optimized Taylor-type rule) because the optimal monetary policy is not aimed at stabilizing wages. Figure 4 also displays the reactions of the nominal interest rate under optimal monetary policy. If there is a supply shock, the nominal interest rate falls in a way similar to that implied by the baseline Taylor-type rule. However, the reaction to a demand shock is much more aggressive with the optimal policy since the nominal interest rate is raised four or five times higher than the level reached with the baseline Taylor-type rule. Such a severe policy tightening leads to a demand contraction that nearly neutralizes the initial expansionary shock. Subsequently, the output gap is practically erased and price inflation stays near 0.

Let us turn to the EHL model for a comparison of optimal monetary policy with household-specific sticky wages. The welfare-theoretic loss function of the EHL model was already obtained by Woodford (2003, chap. 6) and Giannoni and Woodford (2004) as a weighted average of variabilities involving price inflation, wage inflation, and the output gap:

$$\mathcal{L}_t = \lambda_{\pi^p}\left(\pi_t^p\right)^2 + (1-\lambda_{\pi^p})\left(\pi_t^w\right)^2 + \lambda_{\widetilde{y}}(\widetilde{y}_t - \widetilde{y}^*)^2, \tag{42}$$

where the weights on the policy targets are $\lambda_{\pi^p} = \frac{\theta_p \kappa_p^{-1}}{\theta_p \kappa_p^{-1} + \widetilde{\theta}_w (1-\alpha)\kappa_w^{-1}}$ and $\lambda_{\widetilde{y}} = \frac{(\frac{\alpha+\gamma}{1-\alpha}+\sigma)}{\theta_p \kappa_p^{-1} + \widetilde{\theta}_w (1-\alpha)\kappa_w^{-1}}$, with κ_p and κ_w, respectively, denoting the slope coefficients in the price-inflation and wage-inflation equations, (36b) and (37b). Thus, if households are the wage-setting actors, the optimal monetary policy targets wage-inflation variability, which was not included in the loss function of the FSW model. With the numerical values assigned in the baseline calibration (table 2), the stabilizing policy weights in (42) are $\lambda_{\pi^p} = 0.357$ and $\lambda_{\widetilde{y}} = 0.012$. The price-inflation weight indicates that optimal policy should be more oriented to fighting volatility of wage inflation than of price inflation.[39]

The welfare-theoretic targeting rule for the EHL model was derived in appendix 5 by minimizing $E_t \sum_{j=0}^{\infty} \beta^j \mathcal{L}_{t+j}$ subject to the structural equations of the model. Table 6 shows its stabilizing performance. Despite the apparently low value of $\lambda_{\widetilde{y}}$, optimal policy in the EHL model puts the economy very close to the (natural-rate) frictionless scenario because the output gap barely fluctuates. Thus,

[39]This is in deep contrast to the much higher number for λ_{π^p} suggested by Giannoni and Woodford (2004) for the reasons discussed in Casares (2007a).

the standard deviation of the output gap is only 0.03 percent under the welfare-theoretic optimal policy, which seems very low compared with the value of 0.57 percent obtained under the baseline Taylor-type rule (32). Meanwhile, the variabilities of price inflation and wage inflation get moderate reductions when implementing the optimal policy compared with the baseline Taylor-type rule (32). The standard deviation of price inflation falls from 0.89 percent to 0.50 percent and that of wage inflation decreases from 0.50 percent to 0.20 percent.

Using the optimal welfare-theoretic monetary policy and the same criterion mentioned for the case of the FSW model, the optimized coefficients on the Taylor-type rule (32) of the EHL model are[40]

$$\mu^*_{\pi^p} = 39.46, \; \mu^*_{\tilde{y}} = 100.0, \; \text{and } \mu^*_R = 0.72,$$

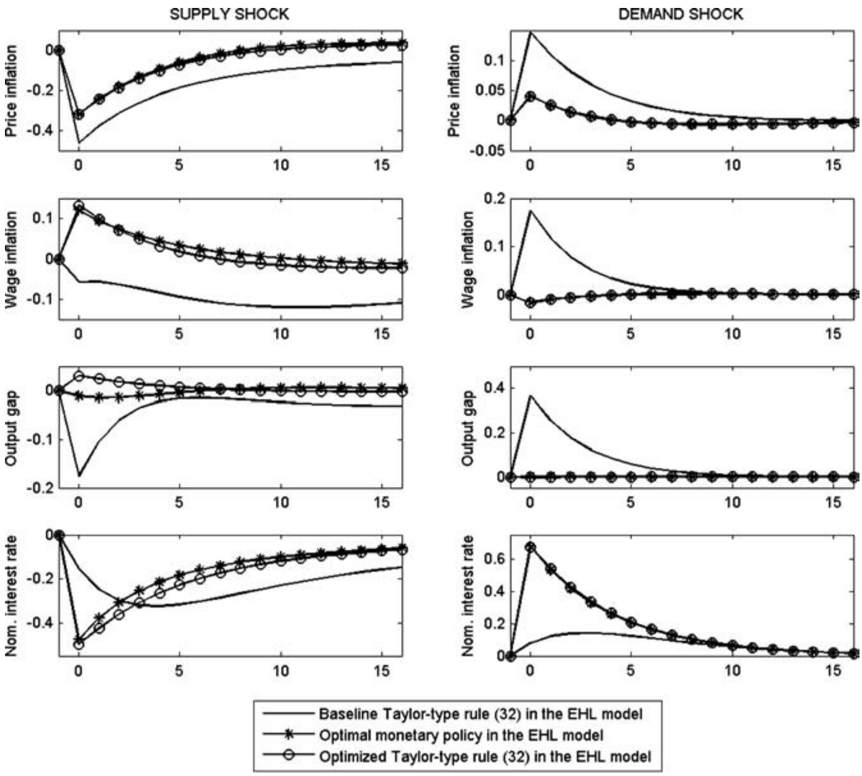
which clearly reflect the major concern of stabilizing the output gap due to its large reaction coefficient, $\mu^*_{\tilde{y}} = 100.0$.

The standard deviations of the targeted variables in the EHL model with the optimized Taylor-type rule (32) are very similar to the numbers obtained with the welfare-theoretic targeting rule. Actually, price inflation has the same volatility, whereas wage inflation and the output gap report only slightly higher numbers (see bottom part of table 6). Unlike the FSW model, the presence of wage inflation in the loss function (42) causes the optimal monetary policy to significantly reduce the wage-inflation volatility. In terms of welfare losses, the ratio of unconditional welfare losses is almost 5 with the baseline calibration of (32), and that can be reduced to only 1.06 (i.e., just a 6 percent higher loss) with the optimized coefficients in (32). Therefore, the Taylor-type rule (32) with $\mu^*_{\pi^p} = 39.46$, $\mu^*_{\tilde{y}} = 100.0$, and $\mu^*_R = 0.72$ approximates fairly well the stabilizing performance achieved with optimal monetary policy.

Impulse-response functions in the EHL model obtained under the three monetary policy rules at hand are shown in figure 5.

[40]The computation of the optimized coefficients was taken with an upper-level bound at 100.0 to avoid excessively large numbers.

Figure 5. Monetary Policy Analysis in the EHL Model: Responses to a Supply Shock (Left) and to a Demand Shock (Right) under Different Monetary Policy Rules



The implementation of the optimized Taylor-type rule (32) leads to responses of the three targeted variables (price inflation, wage inflation, and the output gap) that are very similar to those responses obtained under the optimal monetary policy. The responses under the baseline Taylor-type rule are clearly of larger magnitudes, especially in the case of the output gap. A supply-side technology shock (left side of figure 5) leads to an immediate fall in the nominal interest rate under the optimal monetary policy in order to stimulate output via demand and turn the output gap to the positive side.

As shown on the right side of figure 5, the demand shock also leads to an aggressive interest rate reaction under the welfare-theoretic optimal rule of the EHL model. The expansionary shift on the IS curve is almost neutralized by the combination of a higher nominal interest rate with sticky prices that raises the real interest rate. In turn, the positive output gap that was obtained with the baseline Taylor-type rule is swept away, as also occurred in the FSW model. Meanwhile, price inflation and, especially, wage inflation also show much smaller reactions after the shocks when implementing optimal monetary policy.

Comparing the optimal policies displayed in figures 4 and 5, the responses of wage inflation are significantly smaller in the EHL model than in the FSW model with either demand and supply shocks, which reflects the policy preference for stabilizing wage inflation embedded in (42). On the contrary, price inflation responds more strongly to both shocks in the EHL model, because the optimal policy in the FSW model shows a stronger concern for price-inflation stabilization. The output gap shows a larger reaction after a supply shock in the FSW model, whereas it is practically eliminated after a demand shock in both models.

7. Conclusions

This paper shows that the assumption of who set wages (firms or households) in the New Keynesian model with sticky wages is not trivial. If there are firm-specific sticky wages (FSW model), the wage-setting decision depends on the specific pricing conditions of the firm, whereas with household-specific sticky wages, prices and wages are set independently (as in the EHL model).

Several consequences emerge from the price/wage interactions of firm-specific sticky wages. First, the labor market of the FSW model delivers an endogenous measure of unemployment, which was absent in the prominent EHL model. Only the fraction of wage contracts reset over the current period provide a matching between differentiated labor supply and labor demand. The remaining fraction of non-adjusted wages bring disequilibrium between pairs of labor demand and labor supply that, after aggregation, provide endogenous unemployment. Therefore, introducing sticky wages set by firms serves to incorporate unemployment in a New Keynesian model in an alternative way to the presence of search and matching frictions (e.g., Christoffel and Linzert 2005).

Secondly, firm-specific sticky wages have qualitative implications on both price-inflation and wage-inflation dynamics. The gaps of the real wage with respect to labor productivity and the households' marginal rate of substitution (MRS) are the driving forces for fluctuations on both variables in the FSW model. In the EHL model, by contrast, there is a separation between the productivity gap, which only affects price-inflation fluctuations, and the MRS gap, which only determines wage-inflation fluctuations.

Impulse-response functions indicate that output reacts to supply and demand shocks in similar patterns under both sticky-wage specifications. However, the introduction of firm-specific sticky wages becomes crucial for other macroeconomic variables. In addition to the key issue of the absence or presence of unemployment, variables related to the labor market such as wage inflation or the real wage have shown distinctive business-cycle patterns. For example, the FSW model predicts procyclical reactions of the real wage to supply shocks and countercyclical real-wage responses to demand shocks, which is consistent with the empirical arguments pointed out by Sumner and Silver (1989) to explain the mildly procyclical real wages observed in the United States. The Sumner-Silver hypothesis is replicated in the EHL model only in cases when wage stickiness is more persistent than price stickiness.

Finally, firm-specific or household-specific sticky wages also matter for monetary policy analysis. The (welfare-theoretic) optimal monetary policy in the FSW model targets variabilities of price inflation and the output gap, whereas in the EHL model the optimal policy targets are price inflation, wage inflation, and the output gap. In comparative terms, volatilities of wage inflation and the output gap are higher in the optimal monetary policy of the FSW model. By contrast, price inflation has a higher variability in the EHL model. With both sticky-wage specifications, a Taylor-type rule for the nominal interest rate with the original Taylor (1993) coefficients, along with a significant interest-rate-smoothing component, provides a poor approximation to optimal monetary policy. However, the coefficients of such an instrument rule can be optimized with a welfare-based criterion to reach a good stabilizing performance that closely approximates optimal policy.

Appendix 1. Derivation of the Dynamic Relationship between Wage Inflation and Price Inflation, Equation (19), in the Model with Firm-Specific Sticky Wages

The paper shows in section 2 that the subordinate relative wage with Calvo-style rigidities can be written in log-linear terms as follows:

$$\widehat{W}_t(i) - \widehat{W}_t = -\frac{\theta_p}{\theta_w(1-\alpha)}\left(\widehat{P}_t(i) - \widehat{P}_t\right) - \frac{1-\beta\eta}{\theta_w} E_t \sum_{j=0}^{\infty} \beta^j \eta^j u_{t+j}$$
$$+ E_t \sum_{j=1}^{\infty} \beta^j \eta^j \left(\pi_{t+j}^w + \frac{\theta_p}{\theta_w(1-\alpha)} \pi_{t+j}^p\right),$$

which corresponds to equation (16) of the main text. Substituting the relative price and the relative wage for their respective counterparts in terms of price inflation and wage inflation, $\widehat{P}_t(i) - \widehat{P}_t = \frac{\eta}{1-\eta}\pi_t^p$ and $\widehat{W}_t(i) - \widehat{W}_t = \frac{\eta}{1-\eta}\pi_t^w$, we obtain

$$\pi_t^w = -\frac{\theta_p}{\theta_w(1-\alpha)}\pi_t^p - \frac{(1-\beta\eta)(1-\eta)}{\eta\theta_w} E_t \sum_{j=0}^{\infty} \beta^j \eta^j u_{t+j}$$
$$+ \frac{1-\eta}{\eta} E_t \sum_{j=1}^{\infty} \beta^j \eta^j \left(\pi_{t+j}^w + \frac{\theta_p}{\theta_w(1-\alpha)} \pi_{t+j}^p\right).$$

Moving one period forward from the last expression, we can compute $\beta\eta E_t \pi_{t+1}^w$ and then notice that

$$\pi_t^w - \beta\eta E_t \pi_{t+1}^w = -\frac{\theta_p}{\theta_w(1-\alpha)}\left(\pi_t^p - \beta\eta E_t \pi_{t+1}^p\right) - \frac{(1-\beta\eta)(1-\eta)}{\eta\theta_w} u_t$$
$$+ \frac{1-\eta}{\eta}\beta\eta E_t \left(\pi_{t+1}^w + \frac{\theta_p}{\theta_w(1-\alpha)} \pi_{t+1}^p\right),$$

which simplifies to equation (19) in the main text:

$$\pi_t^w = \beta E_t \pi_{t+1}^w - \frac{\theta_p}{\theta_w(1-\alpha)}\left(\pi_t^p - \beta E_t \pi_{t+1}^p\right) - \frac{(1-\beta\eta)(1-\eta)}{\eta\theta_w} u_t.$$

After recursive substitutions of expected next period's wage inflation, we can also obtain this alternative expression of wage inflation:

$$\pi_t^w = -\frac{\theta_p}{\theta_w(1-\alpha)}\pi_t^p - \frac{(1-\eta)(1-\beta\eta)}{\eta\theta_w}E_t\sum_{j=0}^{\infty}\beta^j u_{t+j}.$$

Appendix 2. From the (Log-Linear) Optimal Price (29) to the Phillips Curve (30) in the Model with Firm-Specific Sticky Wages

The log-difference between the optimal price and the aggregate price level is given by equation (29) of the main text,

$$\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)\left(\widehat{P}_t(i)-\widehat{P}_t\right) = (1-\beta\eta)E_t\sum_{j=0}^{\infty}\beta^j\eta^j\left(\widehat{\psi}_{t+j}-\frac{1}{\theta_w}u_{t+j}\right)$$
$$+E_t\sum_{j=1}^{\infty}\beta^j\eta^j\left(\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)\pi_{t+j}^p\right),$$

where we can insert $\widehat{P}_t(i)-\widehat{P}_t = \frac{\eta}{1-\eta}\pi_t^p$ from (17) to yield

$$\pi_t^p = \frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)}E_t\sum_{j=0}^{\infty}\beta^j\eta^j\left(\widehat{\psi}_{t+j}-\frac{1}{\theta_w}u_{t+j}\right)$$
$$+\frac{1-\eta}{\eta}E_t\sum_{j=1}^{\infty}\beta^j\eta^j\pi_{t+j}^p.$$

If we move one period forward from price inflation, premultiply the result by $\beta\eta$, and apply the rational-expectations operator in period t, we obtain

$$\beta\eta E_t\pi_{t+1}^p = \frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)}E_t\sum_{j=1}^{\infty}\beta^j\eta^j\left(\widehat{\psi}_{t+j}-\frac{1}{\theta_w}u_{t+j}\right)$$
$$+\frac{1-\eta}{\eta}E_t\sum_{j=2}^{\infty}\beta^j\eta^j\pi_{t+j}^p.$$

Using the last two expressions, we compute $\pi_t^p - \beta\eta E_t \pi_{t+1}^p$ to find

$$\pi_t^p - \beta\eta E_t \pi_{t+1}^p = \frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)}\left(\widehat{\psi}_t - \frac{1}{\theta_w}u_t\right) + \frac{1-\eta}{\eta}\beta\eta E_t \pi_{t+1}^p,$$

which reduces to the New Keynesian Phillips curve (30),

$$\pi_t^p = \beta E_t \pi_{t+1}^p + \frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)}\left(\widehat{\psi}_t - \frac{1}{\theta_w}u_t\right).$$

Appendix 3. Derivation of the Welfare-Theoretic Loss Function in a New Keynesian Model with Firm-Specific Sticky Wages (FSW Model)

All the approximations taken here are based on second-order Taylor expansions used in Erceg, Henderson, and Levin (2000, 307–12) and Woodford (2003, 692–96).

In the New Keynesian model with wage-setting firms, the household utility function and the social utility function are the same because households are alike. Moreover, the effective amount of bundles of labor services is given by demand conditions. Under this assumption, the values of the utility function (1) in period t can be rewritten in effective terms as follows:

$$U_t = \exp(\chi_t)\frac{c_t^{1-\sigma}}{1-\sigma} - \Psi\frac{n_t^{1+\gamma}}{1+\gamma}, \tag{43}$$

where n_t is the number of effective bundles of labor obtained from the aggregation of the demand for labor services over the continuum of firms:

$$n_t = \left[\int_0^1 n_t^d(i)^{\frac{1+\theta_w}{\theta_w}} di\right]^{\frac{\theta_w}{1+\theta_w}}. \tag{44}$$

Let us separate (43) into its two terms: $V_t = \exp(\chi_t)\frac{c_t^{1-\sigma}}{1-\sigma}$ and $S_t = \Psi\frac{(n_t)^{1+\gamma}}{1+\gamma}$. They can be approximated by the Taylor-series expansions

$$V_t \simeq yU_c\left(\widehat{y}_t + \frac{1}{2}(1-\sigma)\widehat{y}_t^2 + \widehat{y}_t\chi_t\right) \text{ and} \tag{45a}$$

$$S_t \simeq nU_n \left(\widehat{n}_t + \frac{1}{2}(1+\gamma)\widehat{n}_t^2 \right), \tag{45b}$$

where the market-clearing condition $\widehat{c}_t = \widehat{y}_t$ was already used in (45a). The term on disutility from labor bundles, S_t, will be affected by the degree of price/wage dispersion through its impact on fluctuations of the demand for labor bundles, $\widehat{n}_t$. Thus, a Taylor-series expansion on (44) yields

$$\widehat{n}_t \simeq E_i \widehat{n}_t^d(i) + \frac{1}{2}\left(\frac{1+\theta_w}{\theta_w}\right) var_i \widehat{n}_t^d(i), \tag{46}$$

where $E_i \widehat{n}_t^d(i)$ and $var_i \widehat{n}_t^d(i)$, respectively, denote the expected value of the demand for labor and its variance computed across the differentiated firms. Recalling the log-linear production function (10) for the specific i-th firm, we obtain

$$\widehat{n}_t^d(i) = (1-\alpha)^{-1}\widehat{y}_t(i) - z_t,$$

which, aggregating over the i space, implies

$$E_i \widehat{n}_t^d(i) = (1-\alpha)^{-1} E_i \widehat{y}_t(i) - z_t, \tag{47a}$$

$$var_i \widehat{n}_t^d(i) = (1-\alpha)^{-2} var_i \widehat{y}_t(i). \tag{47b}$$

The Dixit-Stiglitz demand function (7) implies that in equilibrium

$$y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta_p} y_t, \tag{48}$$

which leads to the Taylor-series approximation for output fluctuations:

$$\widehat{y}_t \simeq E_i \widehat{y}_t(i) + \frac{1}{2}\frac{\theta_p - 1}{\theta_p} var_i \widehat{y}_t(i). \tag{49}$$

Substituting the pair (47a) and (47b) into (46), we obtain

$$\widehat{n}_t \simeq (1-\alpha)^{-1} E_i \widehat{y}_t(i) - z_t + \frac{1}{2}\left(\frac{1+\theta_w}{\theta_w}\right)(1-\alpha)^{-2} var_i \widehat{y}_t(i),$$

where inserting $E_i\widehat{y}_t(i) = \widehat{y}_t - \frac{1}{2}\frac{\theta_p-1}{\theta_p}var_i\widehat{y}_t(i)$ from (49) yields

$$\widehat{n}_t \simeq (1-\alpha)^{-1}\left(\widehat{y}_t - \frac{1}{2}\frac{\theta_p-1}{\theta_p}var_i\widehat{y}_t(i)\right) - z_t + \frac{1}{2}\left(\frac{1+\theta_w}{\theta_w}\right)(1-\alpha)^{-2}var_i\widehat{y}_t(i).$$

Putting the terms involving $var_i\widehat{y}_t(i)$ together and dropping the exogenous variable z_t, we get

$$\widehat{n}_t \simeq (1-\alpha)^{-1}\widehat{y}_t + \frac{1}{2}(1-\alpha)^{-1}\left(\frac{\alpha+\theta_w^{-1}}{1-\alpha} + \frac{1}{\theta_p}\right)var_i\widehat{y}_t(i). \quad (50)$$

The substitution of (50) into (45b) yields

$$S_t \simeq nU_n\left((1-\alpha)^{-1}\widehat{y}_t + \frac{1}{2}(1-\alpha)^{-1}\left(\frac{\alpha+\theta_w^{-1}}{1-\alpha} + \frac{1}{\theta_p}\right)var_i\widehat{y}_t(i) + \frac{1}{2}(1+\gamma)\widehat{n}_t^2\right),$$

where using $\widehat{n}_t^2 = (1-\alpha)^{-2}\widehat{y}_t^2 - 2(1-\alpha)^{-1}\widehat{y}_t z_t + z_t^2$ from the log-linear production function (10) results in

$$S_t \simeq nU_n\left((1-\alpha)^{-1}\widehat{y}_t + \frac{1}{2}(1-\alpha)^{-1}\left(\frac{\alpha+\theta_w^{-1}}{1-\alpha} + \frac{1}{\theta_p}\right)var_i\widehat{y}_t(i)\right) + nU_n\left(\frac{1}{2}(1+\gamma)\big((1-\alpha)^{-2}\widehat{y}_t^2 - 2(1-\alpha)^{-1}\widehat{y}_t z_t + z_t^2\big)\right). \quad (51)$$

Following Woodford (2003, chap. 6), the steady-state solution of the model implies the relationship $nU_n = yU_c(1-\alpha)(1-\Phi_y)$, where $1-\Phi_y$ represents the market-power distortion calculated as the inverse of the steady-state markup of the real wage over the marginal product of labor.[41] This result can be used in (51) to obtain (dropping the z_t^2 exogenous term)

$$S_t \simeq yU_c(1-\Phi_y)\left(\widehat{y}_t + \frac{1}{2}\left(\frac{\alpha+\theta_w^{-1}}{1-\alpha} + \frac{1}{\theta_p}\right) var_i\widehat{y}_t(i)\right)$$
$$+ yU_c(1-\Phi_y)\left(\frac{1}{2}(1+\gamma)(1-\alpha)^{-1}\widehat{y}_t^2 - \widehat{y}_t(1+\gamma)z_t\right). \quad (52)$$

Using (45a) for V_t and (52) for S_t, the social utility function (43) can be approximated (after some algebra) by

$$U_t \simeq yU_c\left(\Phi_y\widehat{y}_t - \frac{1}{2}\varpi^{-1}\widehat{y}_t^2 + \widehat{y}_t((1+\gamma)z_t + \chi_t)\right.$$
$$\left. -\frac{1}{2}\left(\frac{\alpha+\theta_w^{-1}}{1-\alpha} + \frac{1}{\theta_p}\right) var_i\widehat{y}_t(i)\right), \quad (53)$$

where $\varpi = \frac{1-\alpha}{\sigma(1-\alpha)+\alpha+\gamma}$ and the terms $\Phi_y\widehat{y}_t^2$, $\Phi_y\widehat{y}_t((1+\gamma)z_t+\chi_t)$, and $\Phi_y var_i\widehat{y}_t(i)$ were neglected as being of order higher than 2 as in Woodford (2003, 393–94). Let us define the relative-to-efficiency output gap as

$$\widetilde{y}_t - \widetilde{y}^* = (\widehat{y}_t - \widehat{\overline{y}}_t) - \widetilde{y}^*, \quad (54)$$

where, again following Woodford (2003, 395), $\widetilde{y}^*$ is the efficient level of the output gap obtained as the fractional difference in steady state between the level of output produced in a perfectly competitive economy and the level of potential output obtained in a monopolistically competitive economy, i.e., $\widetilde{y}^* = \log(\frac{y^*}{\overline{y}})$. For the FSW model described in the text, we have $\widetilde{y}^* = -\varpi\log(1-\Phi_y) \simeq \varpi\Phi_y$, where ϖ completely depends on the values of parameters regarding preferences and technology as defined above and $\Phi_y = \theta_p^{-1}$. From $(\widetilde{y}_t - \widetilde{y}^*)^2$ implied by (54) and $\widetilde{y}^* = \varpi\Phi_y$, the square output fluctuations, $\widehat{y}_t^2$, can be written as follows:

$$\widehat{y}_t^2 = (\widetilde{y}_t - \widetilde{y}^*)^2 + 2\widehat{y}_t\widehat{\overline{y}}_t - \widehat{\overline{y}}_t^2 - (\varpi\Phi_y)^2 + 2\varpi\Phi_y\widehat{y}_t - 2\varpi\Phi_y\widehat{\overline{y}}_t, \quad (55)$$

[41]Note that in the FSW model, $\Phi_y = \theta_p^{-1}$ and $1-\Phi_y = \frac{\theta_p - 1}{\theta_p}$.

where potential output fluctuations are $\widehat{\overline{y}}_t = \varpi((1+\gamma)z_t + \chi_t)$ as in equation (33) of the text. Inserting (55) into (53), we obtain the following (after dropping constant and exogenous terms):

$$U_t \simeq -\frac{yU_c}{2}\left(\varpi^{-1}(\widetilde{y}_t - \widetilde{y}^*)^2 + \left(\frac{\alpha+\theta_w^{-1}}{1-\alpha} + \frac{1}{\theta_p}\right) var_i \widehat{y}_t(i)\right). \quad (56)$$

By log-linearizing (48), the variance on differentiated output can be expressed in terms of price dispersion:

$$var_i \widehat{y}_t(i) = \theta_p^2 var_i \widehat{P}_t(i),$$

which leaves (56) as follows:

$$U_t \simeq -\frac{yU_c}{2}\left(\varpi^{-1}(\widetilde{y}_t - \widetilde{y}^*)^2 + \theta_p\left(1 + \frac{\theta_p\big(\alpha+\theta_w^{-1}\big)}{1-\alpha}\right) var_i \widehat{P}_t(i)\right).$$

Accordingly, the central bank intertemporal (social) utility function $\sum_{j=0}^{\infty} \beta^j E_t U_{t+j}$ becomes

$$\sum_{j=0}^{\infty} \beta^j E_t U_{t+j} \simeq -\frac{yU_c}{2}\sum_{j=0}^{\infty} \beta^j E_t \Bigg(\varpi^{-1}(\widetilde{y}_{t+j} - \widetilde{y}^*)^2 + \theta_p\left(1 + \frac{\theta_p\big(\alpha+\theta_w^{-1}\big)}{1-\alpha}\right) var_i \widehat{P}_{t+j}(i)\Bigg). \quad (57)$$

Applying the results of Woodford (2003, 694–96), due to our Calvo-style sticky-price structure, we obtain

$$var_i \widehat{P}_t(i) \simeq \eta var_i \widehat{P}_{t-1}(i) + \frac{\eta}{1-\eta}\big(\pi_t^p\big)^2,$$

which implies

$$\sum_{j=0}^{\infty} \beta^j E_t var_i \widehat{P}_{t+j}(i) \simeq \frac{\eta}{(1-\eta)(1-\beta\eta)}\sum_{j=0}^{\infty} \beta^j E_t \big(\pi_{t+j}^p\big)^2. \quad (58)$$

Combining (57) and (58), we obtain

$$\sum_{j=0}^{\infty} \beta^j E_t U_{t+j} \simeq -\frac{yU_c}{2} \sum_{j=0}^{\infty} \beta^j E_t \left(\varpi^{-1} (\widetilde{y}_{t+j} - \widetilde{y}^*)^2 + \frac{\theta_p \left(1 + \frac{\theta_p \left(\alpha + \theta_w^{-1}\right)}{1-\alpha}\right) \eta}{(1-\eta)(1-\beta\eta)} \left(\pi_{t+j}^p\right)^2 \right),$$

which can be reorganized as follows:

$$\sum_{j=0}^{\infty} \beta^j E_t U_{t+j} \simeq -\Xi \sum_{j=0}^{\infty} \beta^j E_t \left(\left(\pi_{t+j}^p\right)^2 + \varpi^{-1} \frac{(1-\eta)(1-\beta\eta)}{\theta_p \left(1 + \frac{\theta_p \left(\alpha + \theta_w^{-1}\right)}{1-\alpha}\right) \eta} (\widetilde{y}_{t+j} - \widetilde{y}^*)^2 \right),$$

with $\Xi = \frac{yU_c}{2} \frac{\theta_p \left(1 + \frac{\theta_p (\alpha + \theta_w^{-1})}{1-\alpha}\right) \eta}{(1-\eta)(1-\beta\eta)}$. Our last result implies that the central bank loss function for period t is

$$L_t = \left(\pi_t^p\right)^2 + \lambda (\widetilde{y}_t - \widetilde{y}^*)^2,$$

with $\lambda = \frac{(1-\eta)(1-\beta\eta)(\frac{\alpha+\gamma}{1-\alpha} + \sigma)}{\eta \left(1 + \frac{\theta_p (\alpha + \theta_w^{-1})}{1-\alpha}\right) \theta_p}$ as defined in section 6 for the output-gap weight in the welfare-theoretic loss function of the FSW model.

Appendix 4. Welfare-Theoretic Targeting Rule in the FSW Model

Using the "timeless perspective" optimality criterion (Woodford 1999, 18), optimal monetary policy can be reached by computing the targeting rule that minimizes the intertemporal welfare-theoretic loss function subject to a set of equations describing the FSW model. Formally, it can be written as follows:

$$\underset{\pi_t^p, \widetilde{y}_t, u_t, \widehat{w}_t, \pi_t^w}{Min} \quad E_t \sum_{j=0}^{\infty} \beta^j L_{t+j}$$

subject to these all-time constraints:

$$\pi^p_{t+j} = \beta E_{t+j}\pi^p_{t+1+j} + \phi_1\left(\widehat{w}_{t+j} + \frac{\alpha}{1-\alpha}\widetilde{y}_{t+j}\right) - \frac{\phi_1}{\theta_w}u_{t+j} + \varkappa^{\pi^p}_{t+j}, \tag{59}$$

$$u_{t+j} = \frac{1}{\gamma}\widehat{w}_{t+j} - \phi_2\widetilde{y}_{t+j} + \varkappa^u_{t+j}, \tag{60}$$

$$\pi^w_{t+j} = \beta E_{t+j}\pi^w_{t+1+j} - \frac{\theta_p}{\theta_w(1-\alpha)}\left(\pi^p_{t+j} - \beta E_{t+j}\pi^p_{t+1+j}\right) - \phi_3 u_{t+j}, \tag{61}$$

$$\widehat{w}_{t+j} = \widehat{w}_{t-1+j} + \pi^w_{t+j} - \pi^p_{t+j}, \tag{62}$$

for $j = \ldots, -2, -1, 0, 1, 2, \ldots$. Equation (59) is the inflation equation (30) from the text written for period $t+j$ because it should be noted that $\phi_1 = \frac{(1-\eta)(1-\beta\eta)}{\eta\left(1+\frac{\theta_p(\alpha+\theta_w^{-1})}{1-\alpha}\right)}$, $\widehat{\psi}_{t+j} = \widehat{w}_{t+j} - \widehat{mpl}_{t+j} = \widehat{w}_{t+j} + \frac{\alpha}{1-\alpha}\widehat{y}_{t+j} = \widehat{w}_{t+j} + \frac{\alpha}{1-\alpha}(\widetilde{y}_{t+j} + \widehat{\overline{y}}_{t+j})$, and $\varkappa^{\pi^p}_{t+j} = \phi_1\frac{\alpha}{1-\alpha}\widehat{\overline{y}}_{t+j}$. Next, (60) relates the unemployment rate to real-wage fluctuations, the output gap, and the exogenous term $\varkappa^u_{t+j} = -\phi_2\widehat{\overline{y}}_{t+j} + z_{t+j} + \frac{1}{\gamma}\chi_{t+j}$ with $\phi_2 = \frac{\sigma(1-\alpha)+\gamma}{\gamma(1-\alpha)}$. Some algebra is involved in the determination of (60). In short, the unemployment rate (15) can be decomposed in $u_{t+j} = (\widehat{n}^s_{t+j} - \widehat{\overline{n}}_{t+j}) + (\widehat{\overline{n}}_{t+j} - \widehat{n}_{t+j})$, where the second term is $(\widehat{\overline{n}}_{t+j} - \widehat{n}_{t+j}) = -\frac{1}{1-\alpha}\widetilde{y}_{t+j}$. Using the log-linear version of the labor-supply curve (5) both in current and flexible-price observations, we find $\widehat{n}^s_{t+j} - \widehat{\overline{n}}_{t+j} = \frac{1}{\gamma}\widehat{w}_{t+j} - \frac{\sigma}{\gamma}\widetilde{y}_{t+j} + \varkappa^u_{t+j}$, which, substituted for the first term of the unemployment decomposition, yields (60). Next, the wage-inflation equation of the FSW model, equation (19), has been adapted to period $t+j$ to be written in the form of (61) with $\phi_3 = \frac{(1-\eta)(1-\beta\eta)}{\eta\theta_w}$. Finally, the auxiliary equation (62) was already introduced in the text as equation (40). For the optimal monetary policy conducted in period t, the central bank first-order conditions are

$$2\pi^p_t + \xi^{\pi^p}_t - \xi^{\pi^p}_{t-1} + \frac{\theta_p}{\theta_w(1-\alpha)}\xi^{\pi^w}_t - \frac{\theta_p}{\theta_w(1-\alpha)}\xi^{\pi^w}_{t-1} + \xi^w_t = 0, \tag{63}$$

$$2\lambda(\widetilde{y}_t - \widetilde{y}^*) - \phi_1\frac{\alpha}{1-\alpha}\xi^{\pi^p}_t + \phi_2\xi^u_t = 0, \tag{64}$$

$$\frac{\phi_1}{\theta_w}\xi_t^{\pi^p} + \xi_t^u + \phi_3 \xi_t^{\pi^w} = 0, \quad (65)$$

$$-\phi_1 \xi_t^{\pi^p} - \frac{1}{\gamma}\xi_t^u + \xi_t^w - \beta E_t \xi_{t+1}^w = 0, \quad (66)$$

$$\xi_t^{\pi^w} - \xi_{t-1}^{\pi^w} - \xi_t^w = 0, \quad (67)$$

where $\xi_t^{\pi^p}$, ξ_t^u, $\xi_t^{\pi^w}$, and ξ_t^w are the Lagrange multipliers associated with constraints (59)–(62) in period t. The targeting rule that defines the optimal monetary policy consists of equations (59)–(67), which provide solution paths for the nine endogenous variables π_t^p, π_t^w, $\widehat{w}_t$, u_t, $\widetilde{y}_t$, $\xi_t^{\pi^p}$, ξ_t^u, $\xi_t^{\pi^w}$, and ξ_t^w. The IS curve (31) together with the output-gap definition, $\widetilde{y}_t = \widehat{y}_t - \widehat{\overline{y}}_t$, can be added to the system to determine current output and the required move on the nominal interest rate, $\widehat{y}_t$ and R_t.

Appendix 5. Welfare-Theoretic Targeting Rule in the EHL Model

Using the "timeless perspective" optimality criterion (Woodford 1999, 18), optimal monetary policy can be reached by computing the targeting rule that minimizes the intertemporal welfare-theoretic loss function subject to a set of equations describing the EHL model. Formally, it can be written as follows:

$$\underset{\pi_t^p, \widetilde{y}_t, \widehat{w}_t, \pi_t^w}{Min} \quad E_t \sum_{j=0}^{\infty} \beta^j \mathcal{L}_{t+j}$$

subject to these all-time constraints:

$$\pi_{t+j}^p = \beta E_{t+j}\pi_{t+1+j}^p + \varphi_1\left(\widehat{w}_{t+j} + \frac{\alpha}{1-\alpha}\widetilde{y}_{t+j}\right) + \tau_{t+j}^{\pi^p}, \quad (68)$$

$$\pi_{t+j}^w = \beta E_{t+j}\pi_{t+1+j}^w + \varphi_2\left(\left(\frac{\gamma}{1-\alpha} + \sigma\right)\widetilde{y}_{t+j} - \widehat{w}_{t+j}\right) + \tau_{t+j}^{\pi^w}, \quad (69)$$

$$\widehat{w}_{t+j} = \widehat{w}_{t-1+j} + \pi_{t+j}^w - \pi_{t+j}^p, \quad (70)$$

for $j = \ldots, -2, -1, 0, 1, 2, \ldots$. Equation (68) is the New Keynesian Phillips curve of the EHL model, equation (36b), written in terms of π^p_{t+j} because $\varphi_1 = \frac{(1-\eta_p)(1-\beta\eta_p)}{\eta_p(1+\frac{\theta_p}{1-\alpha})}$ and $\tau^{\pi^p}_{t+j} = \varphi_1 \frac{\alpha}{1-\alpha}\widehat{\overline{y}}_{t+j}$. The wage-inflation equation of the EHL model, equation (37b), has been adapted to period $t + j$ to be written in the form of (69), with $\varphi_2 = \frac{(1-\eta_w)(1-\beta\eta_w)}{\eta_w(1+\gamma\widetilde{\theta}_w)}$ and $\varkappa^{\pi^w}_{t+j} = \varphi_2((\frac{\gamma}{1-\alpha}+\sigma)\widehat{\overline{y}}_{t+j} - \frac{\gamma}{1-\alpha}z_{t+j} - \chi_{t+j})$. Finally, the auxiliary equation (70) was already introduced above in (30) for period t. For the optimal monetary policy in period t, the central bank first-order conditions are

$$2\lambda_{\pi^p}\pi^p_t + \xi^{\pi^p}_t - \xi^{\pi^p}_{t-1} + \xi^w_t = 0, \tag{71}$$

$$2\lambda_{\widetilde{y}}(\widetilde{y}_t - \widetilde{y}^*) - \varphi_1 \frac{\alpha}{1-\alpha}\xi^{\pi^p}_t - \varphi_2\left(\frac{\gamma}{1-\alpha} + \sigma\right)\xi^{\pi^w}_t = 0, \tag{72}$$

$$-\varphi_1\xi^{\pi^p}_t + \varphi_2\xi^{\pi^w}_t + \xi^w_t - \beta E_t\xi^w_{t+1} = 0, \tag{73}$$

$$\xi^{\pi^w}_t - \xi^{\pi^w}_{t-1} - \xi^w_t = 0, \tag{74}$$

where $\xi^{\pi^p}_t$, $\xi^{\pi^w}_t$, and ξ^w_t are the Lagrange multipliers associated with constraints (68)–(70) in period t. The targeting rule that defines the optimal monetary policy in the EHL model consists of equations (68)–(74), which provide solution paths for the seven endogenous variables π^p_t, π^w_t, $\widehat{w}_t$, $\widetilde{y}_t$, $\xi^{\pi^p}_t$, $\xi^{\pi^w}_t$, and ξ^w_t. The IS curve (31) together with the output-gap definition, $\widetilde{y}_t = \widehat{y}_t - \widehat{\overline{y}}_t$, can be added to the system to determine current output and the required move on the nominal interest rate, $\widehat{y}_t$ and R_t.

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